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Vol. 2

Recommendations to the NRC for Review Criteria for Alternative Methods of Low-Level Radioactive Waste Disposal

Task 2b: Earth-Mounded Concrete Bunkers

Prepared by R. H. Denson, R. D. Bennett, R. M. Wamsley,
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U. S. Army Engineer Waterways Experiment Station

Prepared for
U.S. Nuclear Regulatory
Commission

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Prepared for
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Office of Nuclear Material Safety and Safeguards
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Washington, DC 20555
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ABSTRACT

The U.S. Army Engineers Waterways Experiment Station (WES) and U.S. Army Engineer Division, Huntsville (HNDED) have developed general design criteria and specific design review criteria for the earth-mounded concrete bunker (EMCB) alternative method of low-level radioactive waste (LLW) disposal. An EMCB is generally described as a reinforced concrete vault placed below grade, underneath a tumulus, surrounded by filter-blanket and drainage zones. The tumulus is covered over with a low permeability cover layer and top soil with vegetation.

Eight major review criteria categories have been developed ranging from the loads imposed on the EMCB structure through material quality and durability considerations. Specific design review criteria have been developed in detail for each of the eight major categories.

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CONTENTS

Page

ABSTRACT iii

LIST OF FIGURES x

LIST OF TABLES x

ACKNOWLEDGEMENTS xi

1.0 INTRODUCTION 1-1 1

1.1 Background and Purpose 1-1 1
1.2 Scope 1-1 1
1.3 Description of EMCB 1-2 2

2.0 DESIGN, CONSTRUCTION, AND OPERATION REVEIW CRITERIA 2.1-1 4

2.1 Loads and Load Combinations 2.1-1 4
2.1.1 General Design Criteria for Loads and Load Combinations 2.1-1 4
2.1.2 Specific Design Review Criteria 2.1-1 4
2.1.2.1 Applicable Codes, Standards, and Regulatory Guidance 2.1-1 4
2.1.2.2 Definitions and Nomenclature 2.1-2 5
2.1.2.3 Load Combinations 2.1-2 5
2.2 Structural Design and Analysis 2.2-1 5
2.2.1 General Design Criteria for Structural Design and Analysis 2.2-1 7
2.2.2 Specific Design Review Criteria 2.2-1 7
2.2.2.1 Design and Analysis Procedures 2.2-1 7
2.2.2.2 Stresses 2.2-3 9
2.2.2.3 Structural Acceptance Criteria 2.2-4 10
2.2.2.4 Site Factors Impacting on Design 2.2-4 10
2.3 Construction Materials Quality and Durability 2.3-1 11
2.3.1 Definitions 2.3-1 11
2.3.2 General Design Criteria for Construction Materials Quality and Durability 2.3-2 12
2.3.3 Specific Design Review Criteria 2.3-3 13
2.3.3.1 Concrete and Concrete Materials 2.3-3 13
2.3.3.1.1 Applicable Codes, Standards, and Regulatory Guidance 2.3-3 13
2.3.3.1.2 Portland-Cement Concrete 2.3-5 15
2.3.3.1.3 Rationale Statement for Concrete and Concrete Materials Recommendations 2.3-6 16
2.3.3.2 Moisture Barriers 2.3-7 17
2.3.3.2.1 Applicable Tests, Specifications Standards, and Codes 2.3-7 17
2.3.3.2.2 Coatings and Sealers 2.3-11 21

2.3.3.2.3 Sheet Membranes 2.3-11 21
2.3.3.2.4 Waterstops 2.3-12 22
2.3.3.2.5 Joint Sealants 2.3-13 23
2.3.3.2.6 Bentonite Panels 2.3-13 23
2.3.3.2.7 Rationale Statement for Moisture Barrier Recommendations 2.3-14 24
2.3.3.3 Steel 2.3-15 25
2.3.3.3.1 Applicable Specifications for the Control of Steel 2.3-15 25
2.3.3.3.2 Reinforcing Steel 2.3-15 25
2.3.3.3.3 Structural Steel, Miscellaneous Steel, and Steel-Imbedded Items .. 2.3-15 25
2.3.3.3.4 Rationale for Steel Recommendations 2.3-15 25
2.3.3.4 Shotcrete 2.3-15 25
2.3.3.4.1 Applicable Standards, Specifications, and Tests for the Control of Shotcrete 2.3-16 26
2.3.3.4.2 Shotcrete Composition 2.3-16 26
2.3.3.4.3 Rationale for Using Shotcrete as an Optional Wall Covering 2.3-16 26
2.3.3.5 Geosynthetics 2.3-17 27
2.3.3.5.1 Applicable Documents 2.3-17 27
2.3.3.5.2 Low-Permeability Membranes (Geomembranes) 2.3-17 27
2.3.3.5.2.1 Rationale for the Use of Low-Permeability Membranes 2.3-18 28
2.3.3.5.3 Geotechnical Fabrics (Geotextiles) 2.3-18 28
2.3.3.5.3.1 Rationale for the Use of Geotextiles 2.3-19 29
2.3.3.6 Well Casing, Well Screen, and Drain Pipe 2.3-19 29
2.4 Construction and Operations 2.4-1 30
2.4.1 General Design Criteria Construction and Operations .. 2.4-1 30
2.4.2 Specific Design Review Criteria for Construction and Operations 2.4-1 30
2.4.2.1 Configuration and Dimensions 2.4-7 37
2.4.2.2 Construction Methods 2.4-7 37
2.4.2.2.1 Surveying 2.4-8 38
2.4.2.2.2 Clearing, Grubbing, and Rough Grading 2.4-8 38
2.4.2.2.3 Draining Work Area 2.4-9 39
2.4.2.2.4 Excavating and Preparing Foundation Surface 2.4-9 39
2.4.2.2.5 Installing Foundation Drainage Blanket and Collector Drain 2.4-9 39
2.4.2.2.6 Installing Monitoring Wells 2.4-10 40
2.4.2.2.7 Forming and Formwork 2.4-10 40
2.4.2.2.8 Placing Reinforcement 2.4-11 41
2.4.2.2.9 Forming Joints in Concrete 2.4-11 41
2.4.2.2.10 Proportioning Batching and Mixing of Concrete 2.4-11 41
2.4.2.2.11 Casting Operations 2.4-11 41

2.4.2.2.12 Removing Forms 2.4-12 40
2.4.2.2.13 Placing Moisture Barriers 2.4-12 40
2.4.2.2.14 Placing Waste Packages Inside the Bunkers 2.4-13 41
2.4.2.2.15 Filling Voids Around and Above Waste Packages in the Bunker 2.4-13 41
2.4.2.2.16 Closing and Sealing of Access Openings 2.4-13 41
2.4.2.2.17 Placing and Compacting Fill Adjacent To the EMCB 2.4-14 42
2.4.2.2.18 Placement of Low-Permeability Membranes 2.4-14 42
2.4.2.2.19 Placing Waste Packages in Tumuli 2.4-17 45
2.4.2.2.20 Placing Pervious Backfill Between and Above Waste Packages in Tumuli 2.4-17 45
2.4.2.2.21 Constructing Low-Permeability Backfill 2.4-17 45
2.4.2.2.22 Placing Rock Protection, Topsoil and Establishing Vegetation Over the Completed EMCB............... 2.4-17 45
2.4.2.2.23 Constructing Final Surface Drainage Features 2.4-18 46
2.4.2.2.24 Constructing Record Monuments ... 2.4-18 46
2.4.2.3 Construction Equipment 2.4-18 46
2.4.2.4 Construction, Operations, and Closure Impacts 2.4-20 48
2.4.2.4.1 Roads and Bridges Compatible with Equipment 2.4-20 48
2.4.2.4.2 Construction and Operations Sequence 2.4-20 48
2.4.2.4.3 Worker Safety 2.4-20 48
2.4.2.4.4 Disposal Operations 2.4-20 48-
2.5 Quality Assurance (QA) 2.5-1 49
2.5.1 General Design Criteria for QA on EMCB Construction .. 2.5-1 49
2.5.1.1 Testing of Construction Materials 2.5-1 49
2.5.1.1.1 Concrete 2.5-1 49
2.5.1.1.2 Steel 2.5-2 50
2.5.1.1.3 Geotechnical Materials 2.5-2 50
2.5.1.1.4 Admixtures 2.5-2 50
2.5.1.1.5 Curing Compounds and Curing Membranes 2.5-2 50
2.5.1.1.6 Water 2.5-2 50
2.5.1.1.7 Moisture Barriers 2.5-2 50
2.5.1.2 Verification 2.5-2 50
2.5.1.3 Documentation 2.5-3 51
2.5.2 Specific Construction Inspection Criteria 2.5-3 51
2.5.2.1 Formwork 2.5-4 52
2.5.2.2 Steel - Reinforcement and Embedded Items.... 2.5-4 52
2.5.2.3 Concrete Operations 2.5-4 52
2.6 Structural Performance Monitoring 2.6-1 55

2.6.1 General Criteria for Structural Performance Monitoring 2.6-1 55
2.6.2 Specific Design Review Criteria for Structural Performance Monitoring 2.6-1 55
  2.6.2.1 Types of Measurements 2.6-1 55
  2.6.2.2 Instrument Selection 2.6-2 56
  2.6.2.3 Monitoring Wells 2.6-3 57
    2.6.2.3.1 Well Design 2.6-3 57
      2.6.2.3.1.1 Casing 2.6-3 57
      2.6.2.3.1.2 Joints and Seals 2.6-4 58
      2.6.2.3.1.3 Screen 2.6-4 58
      2.6.2.3.1.4 Soil Backfill 2.6-6 60
    2.6.2.3.2 Maintenance of Wells 2.6-6 60
    2.6.2.3.3 Sampling and Observations 2.6-7 61
  2.6.2.4 Structure Monitoring 2.6-7 61
    2.6.2.4.1 Strains 2.6-7 61
    2.6.2.4.2 Stress 2.6-8 62
    2.6.2.4.3 Deflections 2.6-8 62
    2.6.2.4.4 Settlements 2.6-9 63
    2.6.2.4.5 Joints 2.6-10 64
    2.6.2.4.6 Pore Pressures 2.6-10 64
  2.6.2.5 Data Acquisition Systems 2.6-10 64
  2.6.2.6 Special Considerations and Requirements for Meters Embedded in Concrete 2.6-10 64
    2.6.2.6.1 Inhomogeneity of Concrete 2.6-11 65
    2.6.2.6.2 Shrinkage and Swelling 2.6-11 65
    2.6.2.6.3 Temperature 2.6-11 65
    2.6.2.6.4 Moisture and Corrosion 2.6-11 65
    2.6.2.6.5 Measuring Range and Resolution ... 2.6-11 65
    2.6.2.6.6 Placement and Orientation 2.6-11 65
    2.6.2.6.7 Long-Term Stability and Reliability 2.6-12 66
  2.6.2.7 Limiting Values of Monitored Parameters 2.6-12 66
    2.6.2.7.1 Limits on Structural Deflections 2.6-12 66
    2.6.2.7.2 Limits of Strain for Reinforced Concrete and Steel Reinforcing ... 2.6-13 67
    2.6.2.7.3 Limits for Structural Loads 2.6-13 67
    2.6.2.7.4 Limits for Soil Deformations and Strains 2.6-13 67
      2.6.2.7.4.1 Differential Settlements 2.6-14 68
      2.6.2.7.4.2 Total Settlements ... 2.6-14 68
      2.6.2.7.4.3 Lateral Deformations 2.6-15 69
    2.6.2.7.5 Limits for Soil Loads and Stress 2.6-15 70
  2.6.2.8 Remedial Action Plan 2.6-15 70
  2.6.2.9 Periodic Inspections 2.6-15 70
2.7 Filter and Drainage Systems 2.7-1 70
2.7.1 General Design Criteria for Filter and Drainage Systems 2.7-2 71

2.7.2 Specific Design Review Criteria for Filter and Drainage Systems 2.7-3 72
2.7.2.1 Filters and Drains .... 2.7-3 72'
2.7.2.1.1 Piping and Internal Erosion 2.7-3 72
2.7.2.1.2 Drainage or Permeability 2.7-4 73
2.7.2.1.3 Parallel Gradation Curves for Filter and Protected Soil 2.7-5 74
2.7.2.1.4 Perforated or Slotted Drain Pipe 2.7-5 74
2.7.2.2 Compatibility of Drainage and Filter Materials with the Disposal Environment 2.7-5 74
2.7.2.2.1 Soil 2.7-6 75
2.7.2.2.2 Drain Pipes 2.7-6 76
2.7.2.3 Standards and Test Methods for Drainage Pipe 2.7-8 77
2.7.2.4 Interior Drainage and Collector System 2.7-10 79
2.7.2.4.1 Specific Criteria for Features of the Interior Drainage and Collector System 2.7-10 79
2.7.2.4.2 Free-draining Fill Around Waste Packages 2.7-10 79
2.7.2.4.3 Floors 2.7-10 79
2.7.2.4.4 Interior Collector 2.7-11 80
2.7.2.4.5 Acceptance Tests 2.7-11 80
2.7.2.4.6 Drain Opening 2.7-11 80
2.7.2.4.7 Solid Drain Pipe 2.7-11 80
2.7.2.4.8 Monitored Collector Sump 2.7-11 80
2.7.2.5 Exterior Filter and Drainage Systems 2.7-12 81
2.7.2.5.1 Drain 2.7-12 81
2.7.2.5.1.1 Trench 2.7-12 81
2.7.2.5.1.2 Filter Cloth 2.7-12 81
2.7.2.5.1.3 Perforated Drain Pipe 2.7-15 84
2.7.2.5.1.4 Free-Draining Soil Fill 2.7-15 84
2.7.2.5.1.5 Foundation Drainage Blanket 2.7-15 84
2.7.2.5.1.6 Drainage Zone Within the EMCB 2.7-15 84
2.7.2.5.2 Trench Monitoring Wells 2.7-15 84
2.7.2.6 Placement and Compaction of Free-Draining Fill 2.7-15 84
2.7.2.6.1 Unrestricted Areas 2.7-16 84
2.7.2.6.2 Restricted Areas 2.7-16 86
2.7.2.6.3 Fill Acceptance Criteria 2.7-16 86
2.7.2.6.4 Field Acceptance Test Methods and Frequencies 2.7-17 86
2.7.2.6.5 Certification of Compliance 2.7-18 87
2.8 Waste Cover Systems 2.8-1 89
2.8.1 General Design Criteria for Waste Cover Systems 2.8-1 89
2.8.2 Specific Design Review Criteria for Waste Cover Systems 2.8-1 89
2.8.2.1 Vault Roofs 2.8-1 89

2.8.2.2 Low-Permeability Cover Materials 2.8-3 91
2.8.2.2.1 Low-Permeability Membranes 2.8-3 91
2.8.2.2.2 Low-Permeability Earth Cover 2.8-4 92
2.8.2.2.2.1 Placement and Compaction 2.8-4 92
2.8.2.2.2.1.1 Unrestricted Areas 2.8-4 92
2.8.2.2.2.1.2 Restricted Areas .. 2.8-5 93
2.8.2.2.2.2 Fill Acceptance Criteria 2.8-5 93
2.8.2.2.2.3 Fill Acceptance Test Methods and Frequencies 2.8-5 93
2.8.2.2.2.4 Certification of Compliance 2.8-6 94
2.8.2.3 Topsoil and Vegetation 2.8-6 94

3.0 REFERENCES 3-1 98

APPENDIX A: SUGGESTED FORM WATCHERS REPORT AND PROGRAM A-1 103

LIST OF FIGURES

Page

1.1. Major components of an EMCB 1-3 3
2.3.1. Moisture barriers for concrete 2.3-8 18
2.3.2. Low-permeability membranes applied with overlapping seams 2.3-12 22
2.3.3. Bentonite panels applied to concrete 2.3-14 24
2.4.1. Construction of monolith portions of an earth-mounded concrete bunker 2.4-2 31
2.4.2. Side loading concept of waste emplacement in an EMCB 2.4-15 43
2.4.3. Top loading concept of waste emplacement in an EMCB 2.4-16 44
2.4.4. Example of a record monument 2.4-19 47
2.6.1. Features of sump monitoring wells 2.6-5 59
2.7.1. EMCB filter and drainage system 2.7-2 71
2.7.2. Interior collector and drain system 2.7-13 80
2.7.3. Exterior filter, drain, and collector details 2.7-14 81
2.8.1. Major components of EMCB waste cover system 2.8-2 90

LIST OF TABLES

2.8-1 Typical Rooting Depth of Various Plants 2.8-8 96
2.8-2 Ranking of USCS Soil Types 2.8-9 97

ACKNOWLEDGMENTS

The study reported herein is Task 2b of the U.S. Nuclear Regulatory Commission (NRC) sponsored study entitled, "Technical Assistance in Development of Engineering Criteria and Requirements for Alternative Near-Surface Methods for Disposal of Low-Level Radioactive Waste" (Interagency Number NRC-02-87-006; FIN Number D 1071-1), dated 17 February 1987. The study was performed by personnel of the U.S. Army Engineer Waterways Experiment Station (WES), Structures Laboratory (SL) and Geotechnical Laboratory (GL); and the U.S. Army Engineer Division, Huntsville (HND).

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COL Dwayne G. Lee, CE, was Commander and Director of WES during this study, and Dr. Robert W. Whalin was Technical Director.

-1.0 INTRODUCTION

1.1 Background and Purpose

The Nuclear Regulatory Commission (NRC) Division of Low-Level Waste Management and Decommissioning (LLWM) requested assistance from the US Army Engineer Waterways Experiment Station (WES) and the U.S. Army Engineer Division, Huntsville (HNDED) in the development of regulatory guidance and technical criteria to be used to evaluate license applications for alternative methods of near-surface low-level radioactive waste (LLW) disposal. A draft report entitled "General Design Criteria for Alternative Methods for Disposal of Low-Level Radioactive Wastes (LLW)" has been prepared and previously submitted in the Task 1 portion of this project.

The recommendations and technical guidance given in this report are based on civil engineering experience and good engineering practice. The recommendations for review criteria are intended to result in structures and systems at LLW disposal facilities that provide reasonable assurance for long-term safe performance. These recommendations for review criteria are not regulations and deviations from the criteria are permissible. The acceptability of proposed deviations would need to be reviewed and evaluated by the NRC staff on a case by case basis.

A working draft of the companion report on below-ground vaults (BGV) was provided to the participants of the Ninth Annual DOE Low-Level Radioactive Management Conference on 26 August 1987 in Denver, Colorado. Several groups responded with comments on the working draft. These groups included the Commonwealth of Pennsylvania Department of Environmental Resources, Ebasco Services Incorporated, EG&G Idaho, Incorporated, Rogers and Associates Engineering and the Texas Low-Level Radioactive Waste Disposal Authority. The comments of these organizations were considered and factored into this final report.

1.2 Scope

This report presents recommended specific design review criteria and guidance for the earth-mounded concrete bunker (EMCB) alternative LLW disposal method. EMCB disposal is one of the earth-covered disposal methods for which design criteria are being developed. Another alternative method being considered in this study is the BGV. A separate report identified as Task 2a covers the BGV alternative method of disposal.

In Task 1 of this study, eight major criteria categories were identified and general criteria were developed for these areas. The major categories were:

1. Loads and Load Combinations
2. Structural Design and Analysis
3. Construction Material Quality and Durability
4. Construction and Operations
5. Quality Assurance
6. Structural Performance Monitoring

7. Filter and Drainage Systems
8. Waste Cover Systems

Task 2b, as reported herein, delineates the specific design review criteria and supporting standards, practices, and test methods for the EMCB alternative in each of these major technical categories. For convenience, the General Design Criteria developed in Task 1 have been repeated in this report at the beginning of sections associated with the specific criteria categories.

Facilities and features such as administration buildings, security buildings, lighting, temporary storage areas, landscaping and grading operations that are related to LLW disposal operations, but that are not directly related to the design of disposal units, were not considered in this study. These types of auxiliary facilities are considered to be necessary items for support of a LLW disposal site and can be designed and constructed using accepted conventional methods and materials, but their failure would not result in undue radiological risks to site personnel or to public health and safety.

1.3 Description of EMCB

Major components of an EMCB are shown in Figure 1.1. An EMCB consists of a below-grade reinforced concrete bunker placed in an excavation, below the freeze line, on a pervious foundation blanket with pervious fill material placed adjacent to the walls and roof of the bunker and covered with a low permeability material and an above grade tumulus consisting of waste packages covered with pervious material, a low-permeability soil layer, pervious layer, and capped with a topsoil with vegetation or a rock protection surface. The EMCB includes a drainage system with pipes that are connected to a monitored sump.

Typically, Class C and B waste would be placed in the below-grade concrete bunkers while Class A waste that meets the stability requirements of 10 CFR Part 61.56(b) would be placed in the tumulus.

The design guidance provided in this report is based on the assumption that the 10 CFR Part 61.50(a)(7) site suitability technical requirement has been met and the actual location of the EMCB does provide sufficient depth to the water table such that ground water intrusion, perennial or otherwise, into the waste will not occur.

The purpose of presenting Figure 1.1 is to display the concepts and major components of an EMCB in order to promote a better understanding of the review criteria that are subsequently developed. Presenting the figure is not intended to rigidly limit the designs of EMCB's only to the features shown. It is recognized that specific and unique site, design and construction conditions would encourage variations to be made to the features displayed on Figure 1.1. The NRC staff would review and accept variations and changes, provided the proposed changes resulted in good engineering practice that still permitted the Performance Objectives of 10 CFR, Part 61 to be met.

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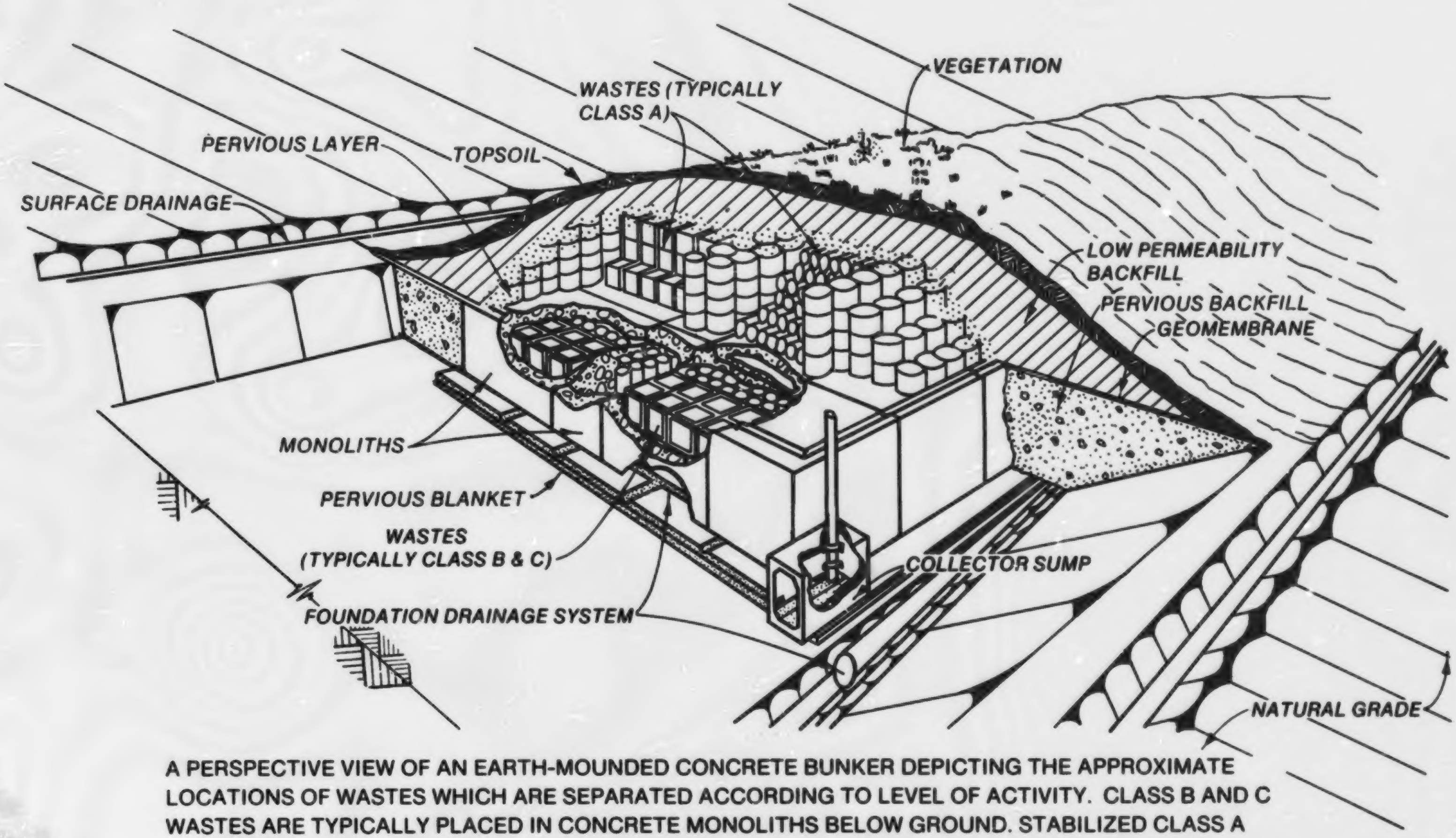
VEGETATION
WASTES (TYPICALLY CLASS A)
PERVIOUS LAYER
TOPSOIL
SURFACE DRAINAGE
LOW PERMEABILITY BACKFILL
PERVIOUS BACKFILL
GEOMEMBRANE
MONOLITHS
PERVIOUS BLANKET
WASTES (TYPICALLY CLASS B & C)
COLLECTOR SUMP
FOUNDATION DRAINAGE SYSTEM
NATURAL GRADE

A PERSPECTIVE VIEW OF AN EARTH-MOUNDED CONCRETE BUNKER DEPICTING THE APPROXIMATE LOCATIONS OF WASTES WHICH ARE SEPARATED ACCORDING TO LEVEL OF ACTIVITY. CLASS B AND C WASTES ARE TYPICALLY PLACED IN CONCRETE MONOLITHS BELOW GROUND. STABILIZED CLASS A WASTES ARE TYPICALLY DISPOSED ABOVE GROUND IN EARTHEN MOUNDS OVER THE CONCRETE MONOLITHS. A DRAINAGE NETWORK IS PROVIDED WITHIN AND AROUND THE STRUCTURE TO PREVENT CONTACT OF WATER WITH THE WASTES AND TO PROVIDE COLLECTION AND MONITORING CAPABILITIES.

Figure 1.1. Major components of an EMCB

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2. DESIGN, CONSTRUCTION, AND OPERATION REVIEW CRITERIA

2.1 Loads and Load Combinations

2.1.1 General Design Criteria for Loads and Load Combinations

a. Structures, structural systems, and structural components essential for safe operation and closure should be designed to withstand anticipated actual loads and load combinations. The loads to be considered should include dead and live loads and loads resulting from naturally occurring events such as earthquakes, storms, tornadoes, floods, tsunamis, hurricanes, and seiches, without failure or loss of capability of the structures, structural systems, and structural components to perform their required safety functions.

b. The loads and load combinations used in the design of structures, structural systems, and structural components that are essential for safe operation and closure should include consideration of appropriate load factors and safety factors, as specified by the codes and standards applicable to such designs. Where such codes and standards are not available or may be inappropriate, designs should be based on sound engineering judgment and accepted practice. The rationale for and justification of deviations from existing codes and standards should be fully documented in writing.

2.1.2 Specific Design Review Criteria

2.1.2.1 Applicable Codes, Standards, and Regulatory Guidance

a. American Concrete Institute (ACI) Standard 349-85, "Code Requirements for Nuclear Safety Related Concrete Structures" (ACI 1987).

b. American Institute of Steel Construction (AISC), Manual of Steel Construction (AISC 1980).

c. American National Standards Institute (ANSI), ANSI A58.1-1982 "Minimum Design Loads for Buildings and Other Structures (ANSI 1982).

d. U.S. Nuclear Regulatory Commission (NRC). NUREG-1199 "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility (NRC 1987a).

e. U.S. Nuclear Regulatory Commission, NUREG-1200 "Standard Review Plan (SRP) for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility" (NRC 1987b).

f. Applied Technology Council, ATC3-06, "Tentative Provisions for the Development of Seismic Regulations for Buildings," (National Bureau of Standards 1978).

g. Local building codes, standards, and regulatory guidance if the requirements are more stringent than the above codes.

2.1.2.2 Definitions and Nomenclature

Normal loads are those loads to be encountered during normal operation, and would consist of:

D - Dead loads or their related internal moments and forces, including any permanent equipment loads. Dead loads should include the weight of structures, structural components, all permanently attached equipment or appurtenances, waste cover materials, backfill, etc.

L - Live loads or their related internal moments and forces, including any moveable equipment loads and other loads which vary in intensity and occurrence, such as soil pressure, snow load, etc. Live loads should include any transient load that is not otherwise specified, such as construction loads, etc.

F - Loads due to lateral and vertical pressure of incidental liquids.

H - Loads due to lateral earth pressure where applicable.

T - Loads which result from temperature differences within the structure. Thermal loads should account for any differential temperature effects that can occur during the design lifetime of the structure.

Severe environmental loads would consist of:

W - Loads generated by the design wind pressure. Wind and snow loads should be developed using the guidance of SRP Section 2.2 of NUREG-1200 in combination with ANSI A58.1.

E - Loads generated by the design basis earthquake. The design basis earthquake load, E, should be determined in accordance with SRP Section 2.3.2 of NUREG-1200.

2.1.2.3 Load Combinations

The strength design method should be used for designing concrete structures. The following load combinations should be used, where the required strength, U, is at least equal to the greatest of the following:

1. $U = 1.4\ D + 1.4\ F + 1.7\ L + 1.7\ H + 1.7\ E$
2. $U = 1.4\ D + 1.4\ F + 1.7\ L + 1.7\ H + 1.7\ W$
3. $U = D + F + L + T + E + H$
4. $U = D + F + L + T + W + H$

For the above load combinations, where any load reduces the effects of other loads, the corresponding coefficient for that load should be taken as 0.9 if it can be demonstrated that the load is always present or occurs simultaneously with the other loads. Otherwise, the coefficient for that load should be taken as zero. Structural steel members should be designed using the elastic working stress in accordance with Manual of Steel Construction, Part I of the "Specification for the Design, Fabrication and Erection of Steel for Buildings" (AISC 1980).

The following load combinations should be used for designing structural steel members where the required strength, S, is at least equal to the greatest of the following:

1. S = D + L
2. S = D + L + E
3. S = D + L + W
4. S = D + L + T + E
5. S = D + L + T + W

For both concrete and steel design, where the effects of differential settlement, creep, or shrinkage are potentially significant, these effects should be included with the dead load.

2.2 Structural Design and Analysis

2.2.1 General Design Criteria for Structural Design and Analysis

a. The structural design of structures, structural systems, and structural components should comply with accepted engineering practice and industrial codes and standards for nuclear structures. At the same time it should provide reasonable assurance of long-term stability and structural integrity, while avoiding the need for active maintenance after closure of the individual disposal units. Limits on stresses, strains, deformations, and other parameters should be identified for comparison with and acceptance in accordance with allowable limits.

b. Structural design should be performed by competent engineering professionals with a successful history of designing important engineering projects.

2.2.2 Specific Design Review Criteria

2.2.2.1 Design and Analysis Procedures

Descriptive information, including plans and sections for each structure and its foundation, should be provided to define the structural aspects and elements. The design and analysis procedures to be used for concrete structures should be in compliance with ACI 349*. For structural steel members and components, the design and analysis should be in compliance with the Specifications of the AISC Manual of Steel Construction (AISC 1980).

ACI 349 has been recommended because its use provides an increased level of conservatism in structural design over the reinforced concrete code requirements of ACI 318 for conventional type buildings. This conservatism is desirable in recognition of the long-term stability requirements of 10 CFR 61.44 which are significantly longer than the expectations of conventional buildings. In addition, ACI 349 identifies the need to establish a quality assurance program that is not included in ACI 318. The NRC staff will provide guidance on quality assurance commensurate with the safety function to be performed by a LLW disposal facility.

In this report, guidance has been given in the use of ACI 349 in recognition of the inherent differences in the level of hazard between a LLW disposal facility and a nuclear power plant facility. As an example, the load combinations previously provided in Section 2.1.2.3 of this report do not require the loadings normally required by ACI 349 from tornado generated missiles or general aircraft missiles.

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* All ACI information is contained in the five-volume ACI Manual of Concrete Practice, revised annually, unless otherwise stated.

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Walls should be designed to sustain and distribute all design loads as well as forces and moments imposed by the continuity of the structural framing system.

Roof systems should be designed to sustain and distribute all design loads, as well as forces and moments imposed by the continuity of the structural framing system. Roof systems should be designed to prevent the buildup, or ponding, of water and infiltration.

Beams and slabs should be designed to sustain and distribute all design loads, as well as forces and moments imposed by the continuity of the structural framing system.

Columns should be designed to sustain all design loads and bending moments imposed by the design conditions.

Floors on grade should be designed to distribute both uniform and non-uniform loads to the foundation or subgrade. When water tightness is required, it should be taken into account in the design.

A minimum thickness of concrete structural members conducive to ease of placement of concrete and steel should be maintained so that dense, low permeability concrete will result.

Documented design and analysis procedures and information should include the following:

a. General assumptions, including boundary conditions and the basis for the assumptions.

b. The expected behavior under loads and the means by which vertical and lateral loads are transmitted from the various elements to their supports and eventually to the foundation of the structure.

c. Descriptions of computer programs, including method of validation, that are used in the design and analysis. Computer programs should be described and validated by one of the following procedures or criteria. A summary comparison should be provided for the results obtained in validation of each computer program.

    1. The computer program is a recognized program in the public domain and has had sufficient history of use to justify its applicability and validity without further demonstration.

    2. The computer program solution to a series of test problems has been demonstrated to be substantially identical to those obtained by a similar and independently written and recognized program in the public domain. The test problems should be demonstrated to be similar to or within the range of applicability of the problems analyzed by the public domain computer program.

3. The computer program solution to a series of test problems has been demonstrated to be substantially identical to those obtained from classical solutions or from accepted experimental tests, or to analytical results published in technical literature. The test problems should be demonstrated to be similar to or within the range of applicability of the classical problems analyzed to justify acceptance of the program.

d. The forces due to the design basis earthquake as defined in SRP 2.3.2 of NUREG-1200 with a description of the method used to calculate these forces. A suitable dynamic analysis method should be used. However, an equivalent static load method may be acceptable if supporting justification is provided that demonstrates the structure has been realistically represented by a simple model and the results of the equivalent method are conservative.

e. A description of the applicant's verification efforts that were employed to check the design, the analytical procedures which were followed, and the correctness and validity of the design calculations.

f. A separate design report containing design and construction information more specific than that normally contained in a Safety Analysis Report (SAR). This report will enable the regulatory agency to perform a structural audit. The design report should contain:

1. Structure Description and Geometry
2. All Pertinent Material Properties for Concrete, Steel, and Foundation Media
3. Structural Loads
4. Design Calculations of Critical Elements Including Drawing and Pertinent Assumptions
5. Summary of Results
6. Conclusions

2.2.2.2 Stresses

The following stress conditions should be evaluated for all applicable design loads and load combinations.

Flexural stresses should be assessed for all structural members which are subject to bending action due to transverse loads, or otherwise. Examples of flexural members would include beams, roof slabs, walls, footings, etc.

Shear and torsion should be assessed for all structural members, particularly those members which resist in plane or transverse loads or both through shear action. Torsional effects should be eliminated as much as possible by designing to obtain symmetry of loading and geometry.

Axial stresses should be assessed for members that resist longitudinal loads, including walls, columns, and beams. Limits on deflections should be such that yielding or buckling of the structural element does not occur and that the element otherwise satisfies all code stress limitations. Calculated deflections due to estimated differential settlement are to be treated as an applied load.

Fatigue due to cyclic loading conditions such as thermal expansion and contraction should be considered, due to the long design lifetime of the facility. If clearly established fatigue limits do not exist, probable limits based on good engineering judgment should be established and justified. Specifically, thermal expansion and contraction should be considered to assure that the functional requirements of the EMCB are met.

Shrinkage and creep in reinforced concrete should be controlled in accordance with guidance contained in ACI 209, "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures" (ACI 1986).

Crack width in reinforced concrete members should be minimized in accordance with provisions of ACI 349 Section 10.6, "Distribution of flexural reinforcement in beams and one-way slabs" (ACI 1987) which prescribes rules for distribution of flexural reinforcement to control flexural cracking.

2.2.2.3 Structural Acceptance Criteria

The EMCB should be checked for all applicable load combinations listed in Section 2.1.2.3 and the stresses should be evaluated on the basis of the following codes:

a. For concrete structures, U is the member strength required to resist design loads based on the strength design methods described in the ACI 349 Code (ACI 1987).

b. For structural steel, S is the member strength required to resist design loads based on elastic design methods and the allowable stresses defined in "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, Part I" (AISC 1980).

2.2.2.4 Site Factors Impacting on Design

Site factors that impact the design and performance of EMCB disposal facilities must be identified and their impacts defined and assessed. These factors are identified and guidance is provided in NUREG-1200 and NUREG-1199. The site factors include geology, seismology, meteorology, climatology, hydrology, geotechnical and geochemical characteristics, natural resources, water resources, and biotic features.

2.3 Construction Materials Quality and Durability

This section addresses the parameters of concern for the quality and durability requirements, and the responses of the materials to these requirements; for portland cement and its components, steel, shotcrete and its components, coatings and sealers, moisture barriers, joint sealants, and geotextiles and membranes.

2.3.1 Definitions

The following definitions apply throughout this report.

a. Portland cement. Portland cement is a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, and usually containing one or more of the forms of calcium sulfate as an interground addition.

b. Portland-cement concrete. Portland-cement concrete is a composite material that consists essentially of a binder mixture of portland cement and water within which are embedded particles or fragments of aggregate and which may or may not contain admixtures.

c. Plain concrete. Plain concrete has no reinforcement and does not conform to the definition of reinforced concrete.

d. Reinforced concrete. Reinforced concrete contains adequate reinforcement (prestressed or not prestressed) and is designed on the assumption that the two materials act together in resisting forces.

e. Prestressed concrete. Prestressed concrete has internal stresses of such magnitude and distribution introduced that the tensile stresses resulting from the service loads are counteracted to a desired degree; in reinforced concrete the prestress is commonly introduced by tensioning the tendons.

f. Precast concrete. Precast concrete is cast elsewhere prior to its final position.

g. Cast-in-place concrete. Cast-in-place concrete is deposited where it is required to harden as part of the structure.

h. Aggregate. Aggregate is any granular material, such as sand, gravel, crushed stone, crushed hydraulic-cement concrete, or iron blast-furnace slag, used with a hydraulic cementing medium to produce concrete or mortar.

i. Admixture. Admixture is a material other than water, aggregates, hydraulic cement, and fiber reinforcement used as an ingredient of concrete or mortar, and added to the concrete batch immediately before or during its mixing.

j. Steel. Steel includes reinforcing, structural, miscellaneous, and imbedded items (other than reinforcing).

k. Moisture barriers. Moisture barriers are those materials that retard liquid migration through the concrete or EMCB components, or otherwise protect any components of the disposal unit against any adverse and deleterious attack.

l. Shotcrete. Shotcrete is mortar or concrete pneumatically projected at high velocity onto a surface; also known as air-blown mortar; also pneumatically applied mortar or concrete, sprayed mortar and gunned concrete. Shotcrete can be produced by either the wet-mix or dry-mix process. The wet-mix process is one in which the ingredients, including water, are mixed before introduction into the delivery hose and an accelerator, if used, is normally added at the nozzle. The dry-mix process is one in which most of the mixing water is added at the nozzle.

These and other definitions are contained in (ACI 1985) Publication SP-19 (85), "Cement and Concrete Terminology," American Concrete Institute; and American Society for Testing and Materials (ASTM), "Compilation of ASTM Standard Definitions," 6th edition, (ASTM 1986b).

2.3.2 General Design Criteria for Construction Materials Quality and Durability

a. Construction materials intended for use in all structures, structural systems, and structural components should be of appropriate composition, quality, and quantity to provide reasonable assurance that structures, systems, and components should function as intended when produced, manufactured, assembled, constructed, or otherwise combined.

b. Structures, structural systems, and structural components should be composed, fabricated, and erected using materials which have been tested and shown to meet standards of quality and durability and which provide reasonable assurance of long-term stability and integrity. The testing methods and procedures from accepted and recognized codes and standards should be identified and evaluated to determine their applicability and adequacy.

c. Where no codes or standards exist or recognized codes and standards do not adequately address certain material quality and durability characteristics, documentation should be provided which delineates the rationale of choice, test methods and data, and/or in-service history, which substantiate or verify the use of nontraditional materials or those for which no standards have been established.

d. The construction materials should meet the requirements of the applicable tests for quality and durability characterization properties, such as resistance to: freezing and thawing, humidity, aging, fatigue, sulfate attack, toxic-material attack, abrasion, temperature changes, wetting and drying, radiation, biodegradation, cracking, electrolysis, fire, and others as may be appropriate.

2.3.3 Specific Design Review Criteria

2.3.3.1 Concrete and Concrete Materials

A concrete mixture for use in the construction of a EMCB should, after curing, be a low-permeability material, capable of safely supporting the loads and resisting the adverse environment, including toxic material attack to which it may be subjected. The following paragraphs give the standards and tests, required materials properties, and rationale for the requirements for the concrete and concrete materials.

2.3.3.1.1 Applicable Codes, Standards, and Regulatory Guidance

The following listed codes, tests, standards, specifications, guides, standard practices, special publications (SP), and recommended practices delineate the information and guidance needed for the control of the quality and durability of concrete and concrete materials anticipated for use in the construction of EMCB. This array of documents (i.e., codes, standards, etc.) provides guidance on, and in some cases provides limiting values for testing, acceptance, specification, and use of concrete and concrete materials, construction practices, and all the other parameter concerns listed in the general design criteria (GDC) (i.e., abrasion, sulfate attack, etc).

a. American Society for Testing and Materials (ASTM 1986a) Test Methods and Specifications,

   (1) C 33 Specification for Concrete Aggregate

   (2) C 39 Test for Compressive Strength of Cylindrical Concrete Specimens

   (3) C 40 Test Method for Organic Impurities in Fine Aggregates

   (4) C 88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

   (5) C 94 Specification for Ready-mixed Concrete

   (6) C 127 Test Method for Specific Gravity and Absorption of Course Aggregate

   (7) C 128 Test Method for Specific Gravity and Absorption of Fine Aggregate

(8) C 131 Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

(9) C 136 Method for Sieve Analysis of Fine and Coarse Aggregates

(10) C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric of Concrete)

(11) C 141 Specification for Hydraulic Lime for Structural Purposes

(12) C 150 Specification for Portland Cement

(13) C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

(14) C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

(15) C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

(16) C 233 Method of Testing Air-Entraining Admixtures for Concrete

(17) C 260 Specification for Air-Entraining Admixtures for Concrete

(18) C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete

b. American Concrete Institute (ACI 1987) Committee Reports, Standards Recommended Practices, Guides, and Specifications:

(1) 117 Standard Tolerances for Concrete Construction and Materials

(2) 201.2 Guide to Durable Concrete

(3) 209 Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures

(4) 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

(5) 212.1 R-81 Admixtures for Concrete

(6) 212.2 R-81 Guide for Use of Admixtures in Concrete

(7) 216 Guide for Determining the Fire Endurance of Concrete Elements

(8) 221 Selection and Use of Aggregates for Concrete

(9) 224 Control of Cracking in Concrete Structures

(10) 301 Specifications for Structural Concrete for Buildings

(11) 350 Concrete Sanitary Engineering Structures

(12) SP-79 Fly Ash, Silica Fume, Slag, and Other Mineral By-Products in Concrete

c. U.S. Army Engineer Waterways Experiment Station, Handbook for Concrete and Cement* (U.S. Army 1949), Requirements, Standard Practices, Tests, and Test Methods:

(1) CRD-C 20 Test Method for Resistance of Concrete to Rapid Freezing and Thawing

(2) CRD-C 28 Test Method for Length Change of Hardened Cement Mortar and Concrete

(3) CRD-C 48 Method of Test for Water Permeability of Concrete

(4) CRD-C 52 Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating - Cutter Method

(5) CRD-C 54 Test Method for Creep of Concrete in Compression

(6) CRD-C 71 Test Method of Ultimate Strain Capacity of Concrete

(7) CRD-C 400 Requirements for Water for Use in Mixing or Curing Concrete

2.3.3.1.2 Portland-Cement Concrete

Portland-cement concrete should be air-entrained and composed of Type V portland cement, water, coarse and fine aggregate, and any admixtures that will desirably enhance the quality and durability, such as silica fume or other appropriate mineral products. Water-reducing admixtures (WRA) should be considered in order to reduce the water-cement ratio (w/c) and yet produce a workable slump. The unconfined compressive strength, f'_c, should be a minimum of 4,000 psi at 28 days age. The concrete should contain 6 to 7 percent air, by volume and have a slump range of 3 to 6 in. without WRA and 6 to 9 in. with WRA. The concrete and concrete materials properties (physical and mechanical) should be established by an approved and certified testing laboratory, based on trial mixtures and using the above appropriate test methods and standards.

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* May be purchased at Technical Reports Distribution, USAE Waterways Experiment Station, Vicksburg, MS 39180-0631.

The portland cement should be Type V meeting the requirements of ASTM C 150. Coarse and fine aggregates should be hard and durable, meeting the requirements of ASTM C 33. The mixing water should be free of oils, other organic impurities, and other deleterious materials, and meet the requirements of CRD-C 400. In general, any potable water might be expected to be acceptable for mixing water.

When aggregates are found to be potentially reactive, in accordance with test ASTM C-289, the cement shall contain not more than 0.60 percent by weight of alkalies ($Na_2O + 0.658\ K_2O$), as indicated in Table 2, ASTM C 150.

Each admixture considered for use in the concrete should meet the applicable requirements for that admixture. Admixtures containing chloride should not be considered because of adverse effects of corrosion of steel when exposed to chloride. A demonstration of the ability of the admixture to enhance the quality and durability of the concrete is required to be submitted to the regulatory agency prior to start of construction. All admixtures should be submitted for acceptance and should be evaluated for effectiveness and feasibility as recommended in ACI 212.2R-81 and ACI 212.

Admixtures, of each individual type, should serve one of the following functions: (1) ensure the proper entrainment of air, (2) allow the regulation of the amount of water, (3) control the time of setting, or (4) act as a void filler (mineral admixtures). All admixtures should be composed of quality materials to ensure that the concrete will perform as expected and to obtain the desired engineering, physical, and mechanical properties.

2.3.3.1.3 Rationale Statement for Concrete and Concrete Materials Recommendations

Type V portland cement should be used for EMCB construction to protect against contamination from the LLW disposal containers or packaging and to provide protection against sulfate and toxic material attack on the concrete and chloride attack on the reinforcing steel. However, Type V is not always available in some geographical locations. An alternative to using Type V cement would be to use Type II cement with a partial replacement of the cement with a pozzalan (e.g. fly ash or natural pozzalon), or silica fume or ground iron blast-furnace slag (meeting the requirements of ASTM C 989 "Standard Specifications for Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars"), to produce a concrete that will attain approximately the same unconfined compressive strength, f'_c and sulfate protection as that provided by the use of Type V cement and a low w/c ratio ($\simeq 0.40$). When fly ash is used, the volume of the fly ash should be less than

50 percent of the cementitious material. When silica fume is used, its volume should be less than 15 percent. The use of silica fume, which is very much finer than portland cement and hence has a much higher water demand, could significantly reduce the strength. In order to keep strength within the specified limits, the w/c should be between 0.2 and 0.3 which necessitates the use of a high-range water-reducing admixture (HRWRA) to increase the slump to a value that produces a workable mixture compatible with the placement requirements. The amount of HRWRA to achieve this workability is a function of the amount of silica fume used. The values of silica fume and HRWRA should be determined by trial batches.

The concrete should be air-entrained in order to protect the concrete from the effects of freezing and thawing that may occur during construction and waste disposal operations, when the concrete will be exposed to and unprotected from the environment.

Low-alkali cement must be used where alkali-reactive aggregates are to be used in the concrete mixture.

Based on these recommendations and compliance with the cited codes and standards, a low-permeability concrete should be produced, that should safely contain the waste for the intended time periods.

2.3.3.2 Moisture Barriers

These materials are applied for the purpose of preventing water or other liquids from coming into contact with the concrete and to prevent liquids from passing through the concrete. Most deleterious reactions of concrete require the presence of water for the reaction to occur. The locations of different moisture barriers are shown in Figure 2.3.1.

Examples of commonly used materials are given in the following paragraphs. The selection of one or more materials would need to be selected by license applicant on a case-by-case basis.

2.3.3.2.1 Applicable Tests, Specifications Standards, and Codes

The following listed codes, tests, standards, specifications, guides, standard practices, SP, and recommended practices delineate the information and guidance needed for the control of the quality and durability of coatings and sealers, moisture barriers, and joint sealants anticipated for use in the construction of a EMCB. This array of documents (i.e., codes, standards, etc.) provides guidance for the particular parameters for testing, acceptance, specification, and use of coatings and sealers, moisture barriers, and joint sealants.*

a. American Concrete Institute (ACI 1987), ACI 504R-77, Guide to Joint Sealants for Concrete Structure.

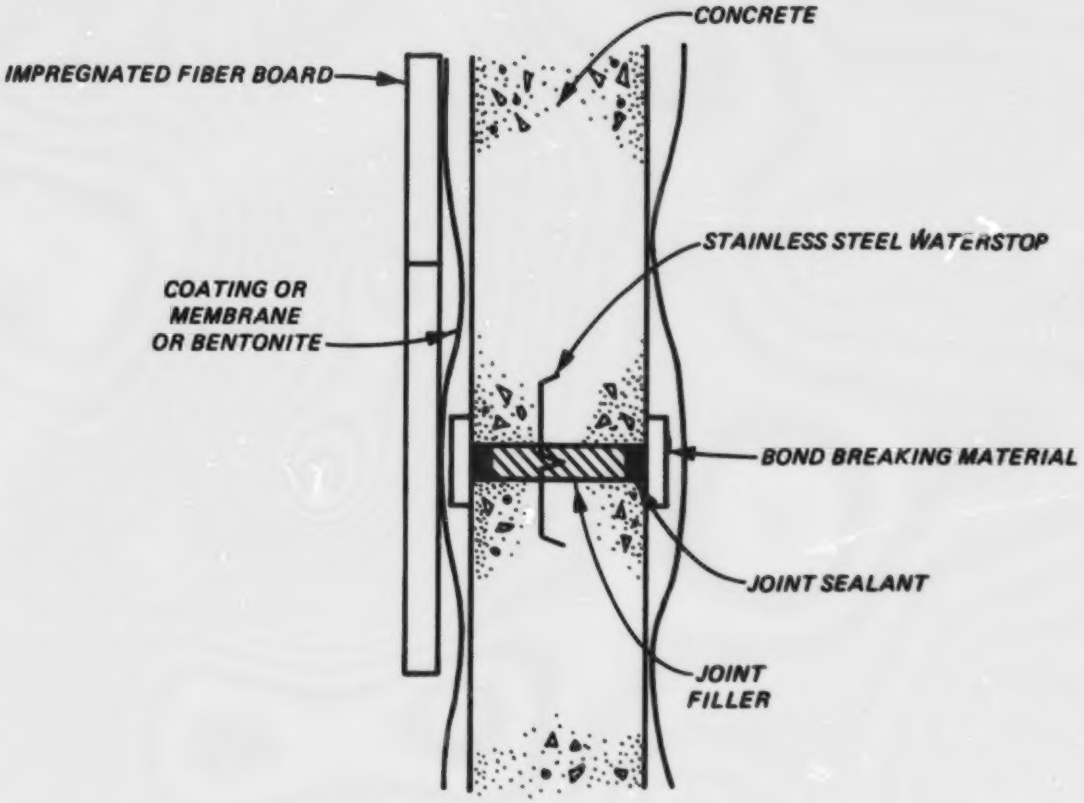
CONCRETE
IMPREGNATED FIBER BOARD
STAINLESS STEEL WATERSTOP
COATING OR MEMBRANE OR BENTONITE
BOND BREAKING MATERIAL
JOINT SEALANT
JOINT FILLER

Figure 2.3.1. Moisture barriers for concrete

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b. American Society for Testing and Materials Standards (ASTM 1986a).

(1) C 836 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use With Separate Wearing Course

(2) C 898 Guide for Use of High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane with Separate Wearing Course

(3) D 41 Specification for Asphalt Primer Used in Roofing, Dampproofing, and Waterproofing

(4) D 43 Specification for Creosote Primer Used in Roofing, Dampproofing, and Waterproofing

(5) D 173 Specification for Bitumen-Saturated Cotton Fabrics Used in Roofing and Waterproofing

(6) D 250 Specification for Asphalt-Saturated Asbestos Felt Used in Roofing and Waterproofing

(7) D 226 Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing

(8) D 227 Specification for Coal-Tar-Saturated Organic Felt Used in Roofing and Waterproofing

(9) D 449 Specification for Asphalt Used in Damp-Proofing and Waterproofing

(10) D 491 Specification for Asphalt Mastic Used in Waterproofing

(11) D 1079 Definitions of Terms Relating to Roofing, Waterproofing, and Bituminous Materials

(12) D 1327 Specification for Bitumen-Saturated Woven Burlap Fabrics Used in Roofing and Waterproofing

(13) D 1654 Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments

(14) D 1668 Specification for Glass Fabrics (Woven and Treated) for Roofing and Waterproofing

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* The type of material selected would dictate which specifications and standards are applicable.

(15) D 2178 Specification for Asphalt Glass Felt Used in Roofing and Waterproofing

(16) D 3020 Specification for Polyethylene and Ethylene Copolymer Plastic Sheeting for Pond, Canal, and Reservoir Lining

(17) D 3083 Specification for Flexible Poly(Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining

(18) D 3254 Specification for Fabric-Reinforced, Vulcanized Rubber Sheeting for Pond, Canal, and Reservoir Lining

(19) D 3393 Specification for Coated Fabrics -- Waterproofness

(20) D 3423 Practice for Application of Emulsified Coal-Tar Pitch (Mineral Colloid Type)

(21) D 3468 Specification for Liquid-Applied Neoprene and Chlorosulfonated Polyethylene Used in Roofing and Waterproofing

(22) D 3843 Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities

(23) D 4258 Practice for Surface Cleaning Concrete for Coating

(24) D 4260 Practice for Acid Etching Concrete

(25) D 4071 Practice for Use of Portland Cement Concrete Bridge Deck Water Barrier Membrane Systems

(26) E-96 Test Methods for Water Vapor Transmission of Materials

(27) E 154-68 Methods of Testing Materials for Use as Vapor Barriers Under Concrete SLABS and as Ground Cover in Crawl Spaces

(28) F 99 Recommended Practice for Preparation of Flexible Barrier Material Specification

c. Corps of Engineers Guide Specification (CEGS)-07112 Bituminous Waterproofing (Corps of Engineers 1986)

d. Federal Test Method Standard SS-A-701B Asphalt, Petroleum (Primer, Roofing, and Waterproofing) (General Service Administration 1974)

e. Federal Construction Guide Specification (FCGS) 07120 Elastomeric Waterproofing System, Fluid-Applied (Federal Construction Council 1986)

f. DOD 4270.21-SPEC Waterproofing and Dampproofing (Department of Defense 1985)

g. ACI 515.1R A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete (ACI 1987)

h. ACI 201.2R Guide to Durable Concrete (ACI 1987)

i. National Concrete Masonry Association (NCMA) TEK 121 Water-Proofing Concrete Masonry Basements and Earth-Sheltered Structures (NCMA 1981)

2.3.3.2.2 Coatings and Sealers

Coatings are usually organic based compounds applied to the surface of concrete to form a protective barrier against aggressive elements. Sealers are usually organic-based compounds mixed with an organic solvent to lower the viscosity so that they will penetrate into the voids in the concrete and when the solvent evaporates, a film is found on the surface and also in the voids of the concrete. Sealers are good materials for concretes that are subjected to abrasions. Some commonly used materials for coatings and sealers are epoxy resin, polyurethanes, and acrylics. These materials would have limited life expectancies of probably less than 100 years. The better coatings are hot applied coal tar or asphalt with fiberglass reinforcement because of their demonstrated performance.

Coating and sealer materials that meet appropriate specifications and standards should be impermeable to moisture, be capable of forming a strong continuous film, have sufficient bond strength to keep them adhered to the surface, and have sufficient tensile strength to prevent tearing and puncturing. The material should have the ability to flow, stretch or deform sufficiently to span any cracks in the concrete after the coating has been formed, be compatible with any other barrier material, joint sealant or adjacent membranes, and be resistant to deleterious agents or elements in the soil and to any leakage from the LLW waste.

2.3.3.2.3 Sheet Membranes

Sheet membranes are usually organic elastomeric material, manufactured into sheets of different sizes and thickness. They are used primarily to prevent water from entering an underground structure. They are usually spliced or seamed at the job to completely cover or encapsulate the submerged portions of the structure. The more commonly used material consists of butyl rubber, neoprene, plasticized polyvinyl chloride (PVC), polyurethane, and rubberized compounds. These materials also have limited short-term life expectancies. It appears that thicker polyethylene sheeting should be a very long-lasting material. Manufacturer test results have projected polyethylene to last over 100 years. The manufacturer indicates that a 300-year life can be expected. Applied membrane is shown in Figure 2.3.2.

A disadvantage of using polyethylenes is degradation caused by exposure to ultraviolet (UV) light. This disadvantage must be considered if the polyethylene is not covered during storage, construction, and operation. Also care should be taken to overcome the difficulty with polyethylene in properly bonding to the concrete surface and forming proper splices during construction.

All sheet membranes meeting the appropriate specifications and standards should be impervious to moisture, have sufficient tensile strength to prevent tearing or puncturing, be composed of a material that will resist biodegradation, oxidation, deleterious effects of water, deleterious effects of radiation, alkalinity, chemical attack, plastic flow, and should have the capacity to form a continuous membrane which will allow encapsulation of the structure. Section 2.3.3.5.2 provides additional information on types and applications of low-permeability membranes.

2.3.3.2.4 Waterstops

Waterstops are usually flexible, water-proofing materials placed in joints in concrete to prevent the passage of water. They are

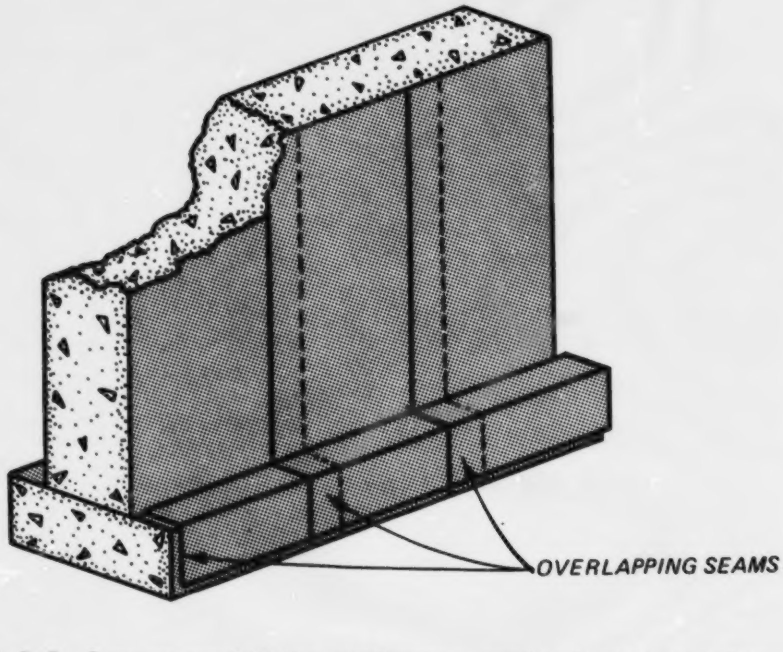

Figure 2.3.2 Low-permeability membranes applied with overlapping seams

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usually cast into the concrete on each side of the joints, which physically locks them into the concrete. The most widely used material is flexible (or plasticized) PVC. However, it is recommended that PVC not be considered for use as a waterstop because of the manufacturer's limited 30-year life warranty for the material.

Type 316 stainless steel should be a very good material to be used as a waterstop. Coal tar or asphalt can be used to coat the expansion portion of the waterstop to further extend the life expectancy. Steel waterstops should be used with joints that have relatively small movement.

2.3.3.2.5 Joint Sealants

The term joint sealant usually refers to flexible materials placed in joints at, or connecting to, the surface of the concrete. They are usually applied to the face of the joint. Joint sealants are generally easier and less expensive to install than waterstops. Some of the more commonly used materials for joint sealants are epoxy resins, polyurethane, acrylics, and rubber compounds. These materials, when used, should be placed in the joint along with the waterstop to extend the amount of time before the waterstops become exposed to the aggressive agents.

Joint sealants, meeting the requirements of appropriate specifications and standards, should be impermeable to moisture and form a seal at the joints or in the concrete to minimize the passage of water or other liquid. The adhesion or mechanical locking should be sufficient to withstand hydrostatic pressures that may be encountered. The sealer material must be capable of accommodating the anticipated design movements of the joints. The material should have the capability to withstand the deleterious efforts of water, alkaline environment, oxygen, ozone, radiation, and biological activity and should be capable of preventing hard objects (e.g. rocks) from entering the joint spaces which could enlarge the joint.

2.3.3.2.6 Bentonite Panels

Bentonite is a naturally occurring clay which can expand up to 20 times its volume when placed in contact with water. The panels are manufactured by forming the clay into 4-ft by 4-ft corrugated cardboard panels. (Bentonite clay is also available in sprayable or trowel applied compounds.) The bentonite should be applied on the surface of the concrete in a manner that will allow it to expand and prevent water from coming into contact with the concrete and to seal any cracks in the concrete if they were to occur. When applied in a proper manner, the bentonite should exceed the life expectancy of the EMCB structure. The overlapping of bentonite panels is shown in Figure 2.3.3.

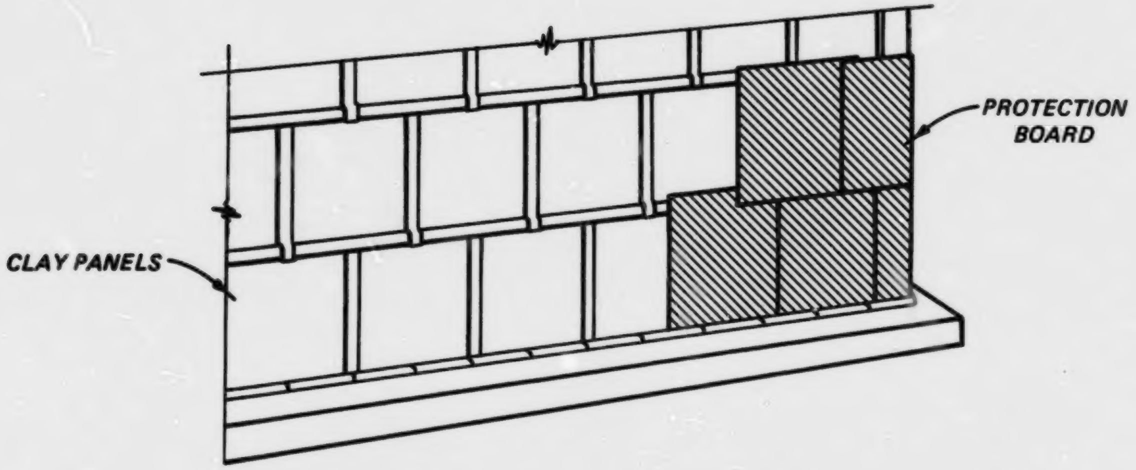

Figure 2.3.3. Bentonite panels applied to concrete

2.3.3.2.7 Rationale for Moisture Barrier Recommendations

A moisture barrier should be applied to the outside and inside surfaces of the structure to protect mainly against water migration and alkali soils (sulfates and chlorides) on the outside and against LLW contamination and moisture migration on the inside of the structure.

Sheet membranes might consist of one or more layers or sheets of rubberized materials attached to the structure or element being protected. Sheet membranes could be considered as a sacrificial multi-barrier system because, being organic, the longevity cannot be fully determined because of the expected radiological and biological interaction and oxidation. The sheet membrane barrier could fulfill its purpose for a given number of years before reliance on the primary barrier would be required.

Joint sealants and waterstops are placed into joints in concrete structures to enable the joints to expand and contract while minimizing the migration of liquids through the structure. The term joint sealant usually refers to materials placed at or connecting to the surface of the concrete. The term waterstop usually refers to a material placed below the surface of the concrete and is physically locked in place in the concrete before it has hardened. Joints sealants placed at the surface are easier and less expensive to install. However, waterstops offer better sealing capacity due to mechanical locking into the concrete.

The type of backfill and the method of placement must be considered to preserve the watertight integrity of the moisture barrier. Sharp objects forcefully placed against the barrier could puncture or tear the surface-applied materials. Some manufacturers recommend that a protective barrier be placed between the moisture barrier and the backfill. They generally recommend impregnated fiber board.

2.3.3.3 Steel

2.3.3.3.1 Applicable Specifications for the Control of the Steel

a. Specification for Deformed and Plain Billet-Steel Bars (ASTM A 615, Grade 60).

b. Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement (ASTM A 616, Grade 60).

c. Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement (ASTM A 617, Grade 60).

d. Specification for Epoxy-coated Reinforcing Steel Bars (ASTM A 775).

e. Specification for Structural Steel (ASTM A 36).

2.3.3.3.2 Reinforcing Steel

Reinforcing steel should meet the requirements of the above referenced standard specifications (ASTM A 615, A 616, and A 617), as appropriate and should be epoxy-coated in accordance with the requirements of ASTM A 775. Bar supports and wire ties should be epoxy-coated.

2.3.3.3.3 Structural Steel, Miscellaneous Steel, and Steel-Imbedded Items

These categories of steel should meet the requirements of ASTM A 36 and should be coated with epoxy or other acceptable coating material for protection against oxidation, corrosion, sulfate and chloride attack, and other deleterious agents.

2.3.3.3.4 Rationale for Steel Recommendations

Because of the nature of the adverse environment from the waste placement in the EMCB and the possibility of contamination and leachate movement from the LLW, all steel items included in the structure should be coated with an acceptable epoxy that is applied by an electrostatic spray method meeting the requirements of ASTM A 775 "Standard Specifications for Epoxy-Coated Reinforcing Steel Bars."

2.3.3.4 Shotcrete

Shotcrete is pneumatically applied concrete or mortar that is capable of supporting itself without sagging or sloughing when properly applied. Shotcrete could be an extra coating or covering to the inside or outside walls and top and the inside floor and roof of the EMCB.

2.3.3.4.1 Applicable Standards, Specifications, and Tests for the Control of Shotcrete

In addition to previously cited standards for concrete and concrete materials should include:

(1) ACI 506.2-77 Specification for materials, proportioning and applications of shotcrete (ACI 1987)

(2) ACI SP-14 Shotcreting (ACI 1966)

(3) ACI SP-54 Shotcrete for ground support (ACI 1977)

(4) ASTM C 494 Specification for Chemical Admixtures for Concrete (ASTM 1986a)

2.3.3.4.2 Shotcrete Composition

The shotcrete should consist of Type V portland cement conforming to ASTM C 150, sand complying with the fine aggregate specified in ASTM C 33, coarse aggregate complying with the requirements of ASTM C 33 and one of the gradings shown in table 202(b) of ACI 506 and water meeting the requirements in CRD C 400. Admixtures used in conjunction with shotcrete should meet the requirements of ASTM C 494, C 260, or C 618 as applicable and are usually categorized as accelerators, air-entraining admixtures, retarders and other water-reducing admixtures, mineral admixtures, and special accelerators. Metallic or nonmetallic fibers, if used in the shotcrete, should meet applicable specifications and standards for the particular material considered.

2.3.3.4.3 Rationale for Using Shotcrete as an Optional Wall Covering

Shotcrete, a durable material that is ideal for applications where less forming is required, is recommended as an optional coating to provide enhancement to the structure in these ways: serve as an aide to watertightness; serve as a sacrificial coating; and, help stabilize the walls. A further optional enhancement to the shotcrete is the addition of metallic or nonmetallic fibers which control or reduce the amount of cracking and increase the flexural strength and impact resistance.

The shotcrete, if used, should be applied to the reinforced concrete structure and cured prior to the application of any other coatings or sealers.

2.3.3.5 Geosynthetics

2.3.3.5.1 Applicable Documents

The following listed codes, tests, standards, specifications, guides, standard practices, SP, and recommended practices delineate the information and guidance needed for the control of the quality and durability of geosynthetics (geotextiles and membranes) anticipated for use in the construction of an EMCB. This array of documents (i.e., codes, standards, etc.) provides guidance for the particular parameters for testing, acceptance, specification, and use of geotextiles and membranes, construction practices, and all other concerns.

a. ASTM documents* (ASTM 1986a)

  (1) D 3786 Test Method for Hydraulic Bursting Strength of Knotted Goods and Nonwoven Fabrics: Diaphragm Bursting Strength Tester Method

  (2) D 4354 Practice for Sampling Geotextiles for Testing

  (3) D 4355 Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc type Apparatus)

  (4) D 4439 Terminology for Geotextiles

  (5) D 4491 Test Methods for Water Permeability of Geotextiles by Permittivity

  (6) D 4533 Text Methods for Trapezoid Tearing Strength of Geotextiles

  (7) D 4594 Effects of Temperature on Stability of Geotextiles

  (8) D 4595 Tensile Properties of Geotextiles by the Wide Width Strip Method

  (9) D 4632 Breaking Load and Elongation of Geotextiles (Grab Method)

2.3.3.5.2 Low-Permeability Membranes (Geomembranes)

Low-permeability membranes, if used, should be designed and constructed of materials that are capable of complementing the capabilities of the low-permeability earth cover and EMCB roof capabilities for minimizing infiltration of water and subsequent contact with waste packages. The membranes should be installed, placed, or embedded in accordance with the manufacturer's recommendations and prevailing construction industry standards. Low-permeability membranes include, but are not limited to, materials in each of the following categories.

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* ASTM is presently developing other applicable tests, specifications, and practices and these should be referred to as appropriate when published by ASTM.

a. Elastomers (rubbers). The most common of the elastomers are butyl rubber, ethylene propylene rubber, ethylene propylene diene monomer, (EPDM), and neoprene.

b. Thermoplastics (plastics). The most common of the thermoplastics are polyethylene (PE), polyvinyl chloride (PVC), and chlorinated polyethylene (CPE).

c. Elastomer - thermoplastic combinations. The most common of the elastomer-thermoplastic combinations are polyethylenes such as low-density (LDPE), high-density (HDPE), and linear low-density (LLDPE) polyethylenes.

2.3.3.5.2.1. Rationale for the Use of Low-Permeability Membranes

Though no standards governing the use of geomembranes have been developed, geomembranes have been used for approximately 25 years, two decades of which have been in waste disposal applications.

The advantages of a polymeric membrane over other hydraulic barrier materials include: (1) a variety of compounds are available; (2) sheeting is produced in a factory environment; (3) polymeric membranes are flexible; and (4) they are relatively simple to install.

Disadvantages of polymeric membranes include: (1) the chemical resistance of the polymeric membrane must be determined for each job; (2) seaming systems are material-dependent and are usually considered the weak link in a membrane; and (3) many polymeric membranes are vulnerable to attack from biotic, mechanical, and environmental sources. Additional information on properties and applications of various geomembranes is given by McAneny and others (USEPA 1985). Probably the best sources of information are the various manufacturers.

The use of low-permeability membranes alone to satisfy design requirements for minimizing infiltration is not recommended because of questions concerning long-term durability.

2.3.3.5.3 Geotechnical Fabrics (Geotextiles)

The term "geotechnical fabric" is defined as an uncoated material, the use of which does not require it to be waterproof (USEPA 1985). Geotechnical fabrics, if used, should be designed and constructed of materials that are capable of complementing the stability of the EMCB and site. Specifically, they may be used to complement and improve the performance of soil drains and filters by acting as a barrier to internal erosion and piping of adjacent finer-grained soil cover materials into the coarser-grained filter soil. Geotextiles should be installed, placed, or embedded in accordance with the manufacturer's recommendations and prevailing industry standards. Geotechnical fabrics are produced from several materials including polypropylene, polyester, polyethylene, nylon, polyvinylidene chloride, and fiberglass, the most common being polypropylene and polyester.

2.3.3.5.3.1 Rationale for the Use of Geotextiles

The use of a geotechnical fabric to complement and improve the performance of drains and filters has become an accepted practice. However, the use of geotextiles alone to satisfy filter and drain criteria is not recommended because of questions concerning long-term durability and performance.

2.3.3.6 Well Casing, Well Screen, and Drain Pipe

Material requirements for well riser casing, well screen, and drainage pipe are discussed in Sections 2.6 and 2.7.

2.4 Construction and Operations

To satisfy the Performance Objectives of 10 CFR Part 61, Subpart C, it is essential that the EMCB be constructed and operated using methods and equipment that are safe and capable of meeting design specifications. Therefore, construction and operations criteria and methods are summarized in this section. The sequence of operations, the operational efforts, and the construction techniques as herein described provide examples of what could have several variations. This section is therefore not intended to be all-inclusive but is intended as guidance to delineate and discuss the major components for construction and operations of an EMCB disposal facility. Figure 2.4.1 illustrates the major steps in construction of an EMCB at the Centre de la Manche. These steps are addressed in Section 2.4.2.2.

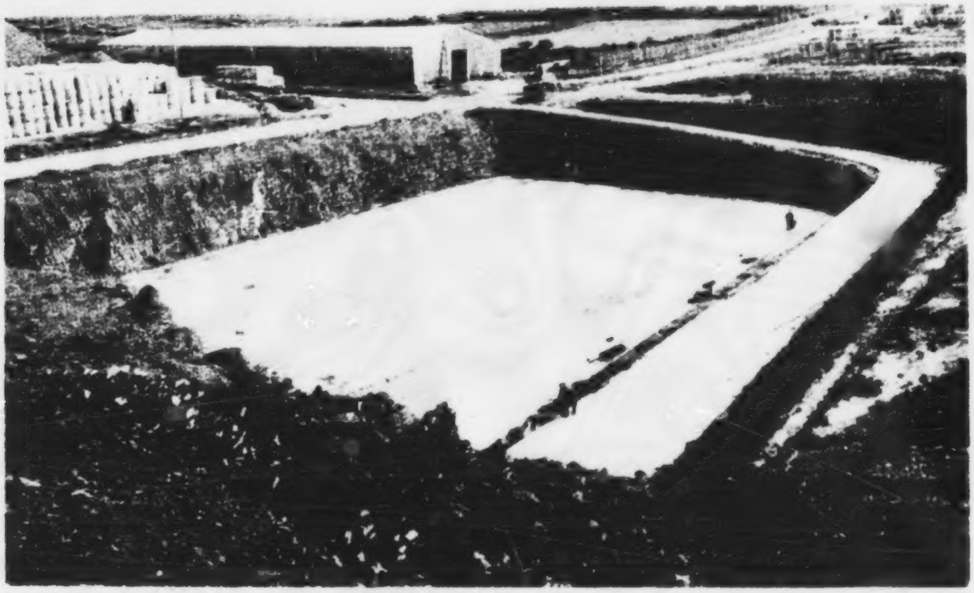
2.4.1 General Design Criteria for Construction and Operations

a. Structures, systems, and components should be constructed using methods and equipment that provide reasonable assurance of a high level of workmanship and competence consistent with established successful construction industry standards.

b. Waste disposal operations should be performed in a manner that provides the highest degree of worker safety reasonably achievable and should not adversely impact the ability of active or adjacent filled or closed disposal units to meet the Performance Objectives of Subpart C of 10 CFR Part 61. Disposal operations should be planned to complement closure of individual units and final site closure.

2.4.2 Specific Design Review Criteria for Construction and Operations

It is intended that the specific design review criteria of this section cover only those portions of construction and operations that are unique to an engineered EMCB structure and that are not covered in NUREG-1199 and NUREG-1200. As an example, the discussions in NUREG-1200, SRP 3.3.1, Construction Methods and Features, that are related to the required information on engineering drawings and site plans (site location, topography, groundwater contours, site boundary, buffer zone, security area, on-site rail and roadways, utility lines, buildings, general layout of disposal units) and on-site preparation and control and diversion of water are not repeated in this section. Construction features and operations unique to EMCB are discussed in this section and cover the construction of reinforced concrete disposal vaults and tumuli and associated waste disposal operations. Other features of EMCB construction are addressed elsewhere in this report (2.5 - Quality Assurance, 2.7 - Filter and Drainage Systems, and 2.8 - Waste Cover Systems).



a. Typical trench excavation

Trench, excavated for construction of an Earth Mounded Concrete Bunker at the Centre de la Manche in France. The bottom of the trench is covered with a layer of coarse pervious material which in turn is covered with a reinforced concrete pad. A drainage network is provided on and around the pad to collect runoff or infiltration which may occur during the construction and initial operation stages.

Figure 2.4.1. Construction of monolith portions of an earth-mounded concrete bunker

Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.

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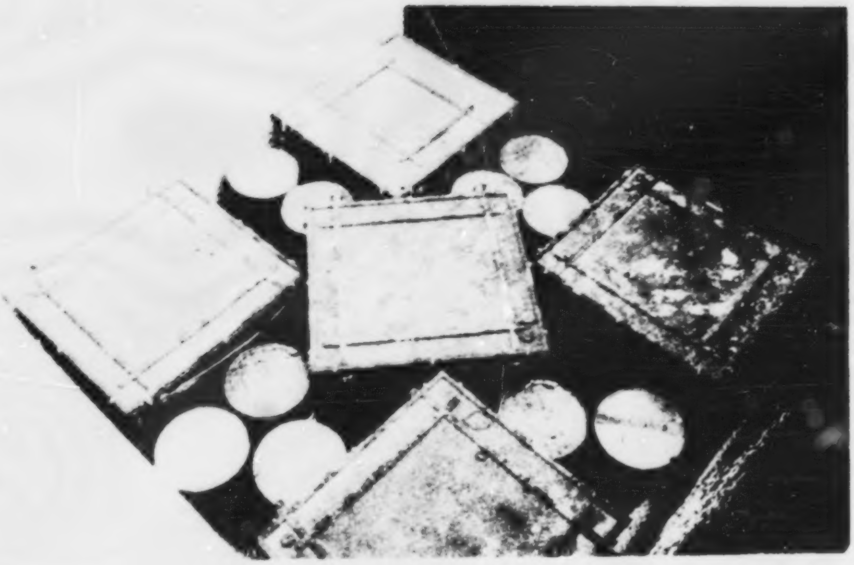

b. Waste placement in monoliths

Waste packages are lowered by crane into compartments in successive layers. After each layer is placed, it is backfilled with pervious backfill.

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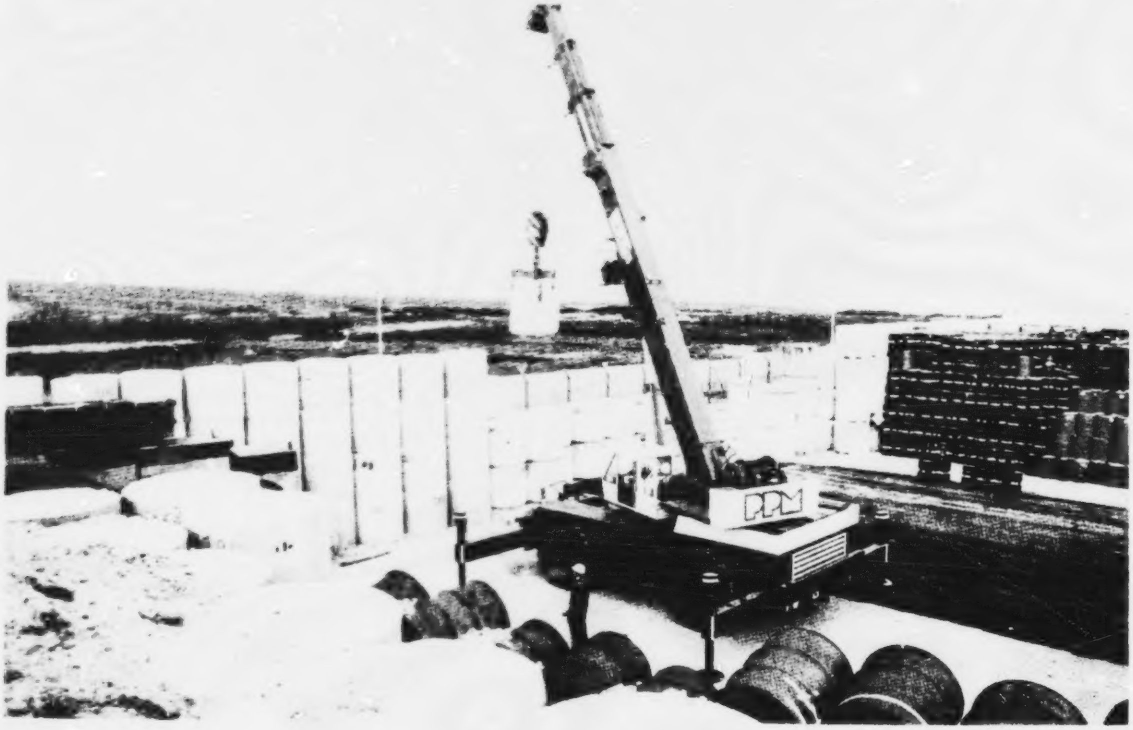
Figure 2.4.1. (Sheet 2 of 5)



c. Structural framework

Construction of the mound or tumulus of an earth-mounded concrete bunker on top of below-grade monoliths at the Centre de la Manche, France. Concrete blocks containing wastes can provide the structural framework of the mound and could be stacked by crane in rows across the middle and around the perimeter.

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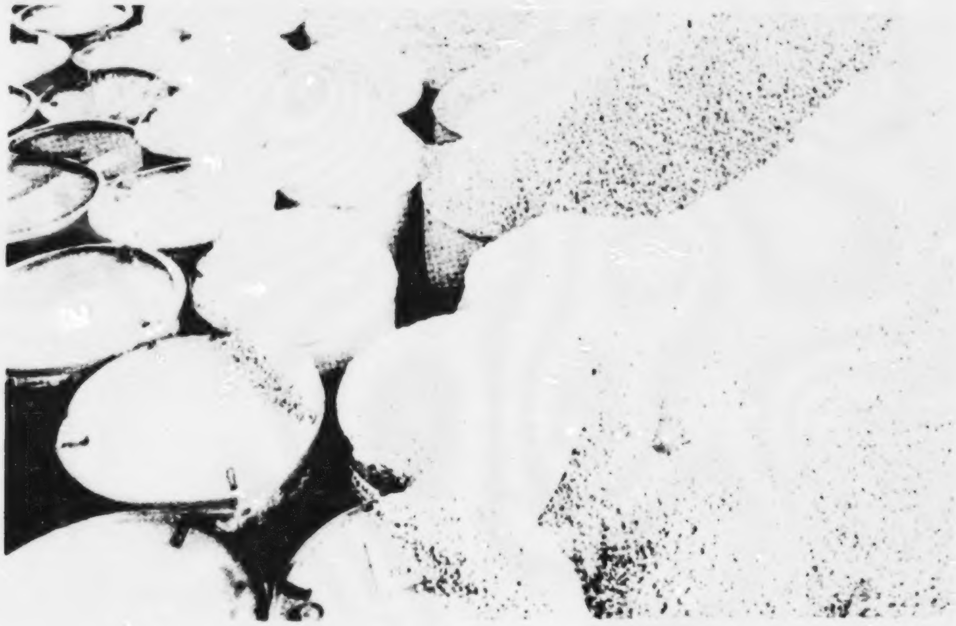
Figure 2.4.1 (sheet 3 of 5)



d. Backfilling of voids between waste packages

Cohesionless backfill material is placed periodically during construction to fill the voids between packages, thus reducing the potential for future settlement, and increasing the stability of the mound.

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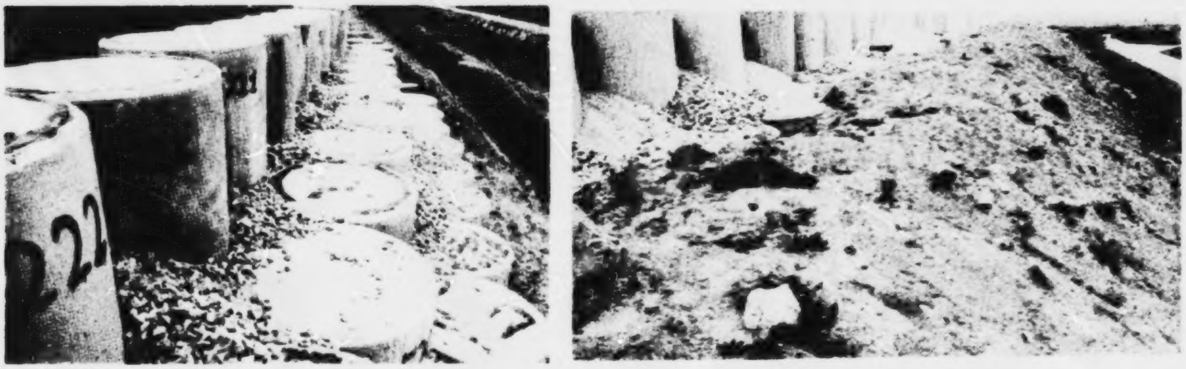
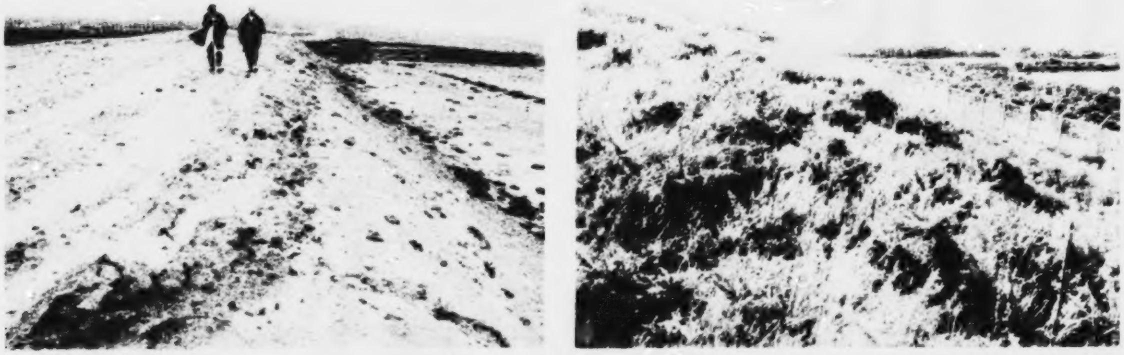
Figure 2.4.1 (Sheet 4 of 5)



(1) Shape of the tumulus is initially formed by staking the waste packages around the perimeter in a stepped arrangement.

(2) The tumulus is built-up using a low permeability material to minimize infiltration.



(3) Final shape of the tumulus is attained after the blocks and compartmentalized wastes have been completely covered.

(4) A completed earth-mounded concrete bunker at the Centre de la Manche, France.

e. Construction sequence of a tumulus

Figure 2.4.1 (Sheet 5 of 5)

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2.4.2.1 Configuration and Dimensions

Selection of physical dimensions and layout and configurations for the EMCB should be based on historical precedents and anticipated quantities, on classifications of wastes to be placed in the disposal units during the expected duration of operations, and on the anticipated sequence of construction operations beginning with off loading of waste through site closure. Dimensions of structural members may be selected to provide excess concrete covering over the reinforcing bars to minimize adverse effects of corrosion and chemical attack due to exposure. If this approach is selected, the thickness of material should be sufficient to provide structural stability with adequate margin for 300 years. Recent work on conceptual designs for alternative methods of LLW disposal (Rogers and Associates, 1987) also provides guidance for selection of dimensions and configurations.

2.4.2.2 Construction Methods

Within reasonable limits, license applicants should be allowed to select construction methods, i.e. a performance specification rather than a method specification should be used. This approach usually encourages innovation without sacrificing performance. If a method specification is used, there must be some mechanism by which deficiencies can be corrected. Appropriate construction methods should be used. The methods are discussed in relation to the major tasks required to construct an EMCB in the following paragraphs. The major tasks are:

a. Site preparation
   1. Surveying.
   2. Clearing, grubbing, and rough grading.
   3. Draining work area.

b. Vault construction
   4. Excavating and preparing foundation surface.
   5. Installing foundation drainage blanket and collector drains.
   6. Installing monitoring wells.
   7. Forming and formwork.
   8. Placing reinforcement.
   9. Forming joints in concrete.
   10. Proportioning, batching, and mixing of concrete.
   11. Casting operations for floors, walls, and partitions which includes placing, vibrating, and curing of portland-cement concrete.
   12. Removing forms.
   13. Placing moisture barriers.
   14. Placing waste packages inside the bunker portion of the EMCB.
   15. Filling voids around and above waste packages in the bunker.
   16. Closing and sealing of access openings.
   17. Placing and compacting fill adjacent to the bunker.
   18. Placing low-permeability membranes.

c. Tumulus construction
  19. Placing waste packages in tumuli.
  20. Placing pervious backfill between and above waste packages in tumuli.
  21. Placing and compacting low permeability backfill around and above the waste packages.
  22. Placing rock protection and/or topsoil and establishing vegetation over the completed EMCB.
  23. Constructing final surface drainage features.
  24. Constructing record monuments.

As mentioned previously, it should be recognized that these tasks and the sequence of construction could vary significantly because of variations in site specific conditions. Many of the above tasks are similar for the construction of near-surface trench-type burial units, and guidance is provided in NUREG-1199 (SFCG) and NUREG-1200 (SRP). Additional comments and guidance are offered below.

2.4.2.2.1 Surveying

Site boundary and topographic surveys prior to design and construction should be performed by a licensed land surveyor. The recommended degree of precision for the boundary survey should be third order. Initial topographic surveys should be performed with stadia method precision, i.e., ± 1 ft horizontal and ± 0.1 ft vertical. In addition to the initial overall site boundary and topographic surveys, boundaries and elevations of individual disposal units should be established to third order precision.

As required by 10 CFR 61.52(a)(7), at least three permanent survey control points should be established on site and referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) control stations to facilitate land surveys. It is recommended that this control network be surveyed to second order precision using mixed triangulation - trilateration observations. These permanent survey control points will also serve as control for the deflection and settlement monitoring discussed in Section 2.6.

2.4.2.2.2 Clearing, Grubbing, and Rough Grading

Clearing, grubbing, and rough grading of the site are necessary for construction of roads, surface drainage features, disposal units and other facilities. Clearing and grubbing consists of removal of trees, shrubs, roots, and organic materials. Rough grading follows clearing and grubbing and results in precontouring to the approximate grade and slope required for all subsequent construction. Clearing and grading plans should clearly show the depths and areas to be cleared, the original and final grades and the disposition of spoil material. Construction methods should be clearly described, including cut and fill practices.

2.4.2.2.3 Draining Work Area

Site drainage should proceed as rough grading proceeds, to promote stable and relatively dry work areas for efficient equipment movement and construction activities. Ditches should be lined with concrete, riprap or sod as required, to minimize erosion. Tucker provides guidance on design of surface erosion control and drainage features. Department of the Army Technical Manual TM-5-818-4, "Backfill for Subsurface Structures," Ch-4, "Earthwork: Excavation and Preparation for Foundations," (June 1983) and Engineer Manual EM-1110-3-136, "Drainage and Erosion Control, Mobilization and Construction," (April 1984) also provide guidance in this area. NUREG-1200 identifies requirements for submittal and acceptance of site drainage plans.

2.4.2.2.4 Excavating and Preparing Foundation Surface

Excavations for the bunker portion of the EMCB would be similar to shallow land burial excavation practices. Excavation slopes should be laid back at safe angles determined through stability analyses with due regard for OSHA safety regulations as the excavation proceeds downward to the foundation level. (NAVFAC DM-7 and Corps of Engineers EM-1110-2-1902, "Stability of Earth and Rockfill Dams," April 1970, and SRP 6.3.2 of NUREG-1200 provide guidance for stability analyses.) The bottom of the excavation should be sloped on a plane towards one side and towards one end to promote collection of drainage.

Loose soil, roots, and other debris materials should be removed from the excavation site and the surface should be proof-rolled to prepare the foundation. Foundation elevations should be surveyed and foundation layer soils should be tested to verify proper foundation elevations and suitable foundation materials. Any soft or weak zones should be over-excavated and replaced with compacted suitable soils. Alternatively, such zones may be treated to improve their load carrying capabilities, subject to the approval of the responsible regulatory agency. Prepared foundation surfaces should be protected against freezing, erosion, and ponding of water. Requirements for flattening of slopes and for excavation to accommodate drainage features and foundations may result in a significant amount of earth volume that may require temporary stockpiling adjacent to the disposal unit excavation. Surcharge loads from this stockpiled earth, as well as loads from excavation equipment must be considered in the design of stable slopes. Department of the Army Technical Manual TM 5-818-4, "Backfill for Subsurface Structures," Ch 4, "Earthwork: Excavation and Preparation for Foundations" (June 1983) provides guidance in this area.

2.4.2.2.5 Installing Foundation Drainage Blanket and Collector Drain

As the excavation for the EMCB is completed, the foundation drainage blanket and perimeter drain and collector sump should be constructed, using suitable equipment and acceptable free draining sand or gravel materials. Specific criteria recommendations for trench excavations for drains and pipes is given in Section 2.7. Specific criteria for filter and drainage layer materials and pipe openings are also provided in Section 2.7 and in the U.S. Army Corps of Engineers Manual (EM), EM-1110-2-1901 (February 1952), Department of the Army Technical Manual TM 5-818-5, "Dewatering and Groundwater Control," (November 1983) and by Tucker (1983). Guidance on selection of drain slopes is provided in Department of the Navy NAVFAC DM-7.

2.4.2.2.6 Installing Monitoring Wells

Monitoring wells should be installed with riser pipes that extend from the foundation drainage layer and interior drain sump to the top surface of the tumulus so that water levels can be measured and water samples can be obtained. One of the most comprehensive references for installation of wells is Groundwater and Wells, 2nd Edition (Driscoll, 1986), published by Johnson Well Division, St. Paul, Minnesota. McAneny and others (US EPA, 1985) and Sedlett and others (1983) provide guidance for installing monitoring wells. Important features of monitoring wells are discussed in more detail in Section 2.6, "Structural Performance Monitoring."

2.4.2.2.7 Forming and Formwork

The applicant should prepare, prior to commencement of work, plans for the construction of forms and formwork for floors, walls, partitions, and roofs for the vault. Guidelines for the layout, design, and construction of formwork are contained in ACI 347, "Recommended Practice for Concrete Formwork," which includes such items as design criteria for vertical and horizontal forces and lateral pressures; design considerations including capacities of formwork accessories; preparation of formwork design drawings; construction and use of forms including safety considerations; and materials for formwork.

The applicant should adhere to the pertinent applicable portions of ACI 347 which include, but are not limited to, safety, construction practices, workmanship, tolerances, shoring, adjustment of formwork, removal of forms and supporting materials for formwork. The forms should be constructed and erected in a manner consistent with industry standards and which will facilitate a logical, well-engineered sequence of construction that will produce the finished product as required. Forms, shoring and bracing should be inspected to verify (1) the adequacy of number and type, (2) correct location, and (3) the required dimensions, alignment and surface finish. The re-use of forms and formwork should be limited to those that will duplicate or equal the required quality of workmanship and finished product.

Holes or depressions left in the adjacent soil by the removal of knee braces, kickers or stakes should be backfilled and hand-tamped to prevent any localized subsidence. Forms should be plumb and set true to line and grade.

2.4.2.2.8 Placing Reinforcement

All reinforcing bars and other embedded items, including form tie wires, should be installed or placed in a manner consistent with good workmanship and applicable standards. The size, cleanliness, location, alignment, embedment depth, and quality of these items should be certified by the applicant prior to concrete placement. The items should be anchored in such a manner that their positions and locations will not be adversely affected by concrete placement and vibration operations.

2.4.2.2.9 Forming Joints in Concrete

The design and placement of joints in concrete should be in accordance with the recommendations and guidance in the following American Concrete Institute (ACI) standards and recommended practices:

224 R Control of Cracking in Concrete Structures: Sections 3.5, 4.2, 4.3, 4.7,

302.1R Guide for Concrete Floor and Slab Construction: Sections 2.3, 3.2, 4.10,

318 Building Code Requirements for Reinforced Concrete: Section 6.4,

349 Code Requirements for Nuclear Safety Related Concrete Structures: Section 6.4.

2.4.2.2.10 Proportioning, Batching and Mixing of Concrete

The concrete mixture should be proportioned in accordance with the provisions of Chapter 5 of ACI 211.1 "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete."

2.4.2.2.11 Casting Operations

The casting operations for the floors, walls, partitions, and roofs of the vaults includes the production of the concrete, hauling of the concrete, placement of concrete into final disposition in the forms, vibration, finishing and curing.

The production, transportation, and placing of concrete, whether job-site produced or produced in an off-site plant, should conform to the recommendation and provisions of ACI 304, Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete. Ready-mixed concrete should comply with ASTM C 94. If the concrete is pumped into final disposition in the forms, the pumping operations and equipment should conform to the provisions of

ACI 304.2, Placing Concrete by Pumping Methods. If the concrete is placed in final disposition in the forms by belt conveyance, the operations and equipment should conform to the provisions of ACI 304.4 Placing Concrete with Belt Conveyors.

Concrete operations during extreme ambient temperatures should conform to either ACI 305, Hot Weather Concreting, or ACI 306, Cold Weather Concreting, whichever is applicable.

The proper consolidation (vibration) of concrete is essential to the construction of a durable concrete structure and therefore consolidation (vibration) operations should conform to the provisions of ACI 309, Standard Practice for Consolidating Concrete.

Once the concrete has been placed and finished, curing operations should be begun at the appropriate time, usually as soon as it loses its surface sheen. The curing operation should conform to the provisions of ACI 308, Standard Practice for Curing Concrete.

Shotcreting operations, if applicable at a particular site for strength and permeability considerations, should conform to ACI 506, Recommended Practice for Shotcrete.

Other recommended guidelines for consideration are suggested to be ACI 117, Standard Tolerances for Concrete Construction and Materials, and ACI 302.1, Guide for Concrete Floor and Slab Construction.

2.4.2.2.12 Removing Forms

Forms should be removed at the time as specified in each job specification for each individual project. Time of form removal should be predicated on the concrete having reached approximately 30 percent of its 28-day compressive strength, as established by a certified and approved testing laboratory. Form removal should be conducted in such a manner that neither forms nor concrete are damaged by removal operations. Forms to be used should be cleaned immediately upon removal, re-oiled, and stored properly. Defects, if any, in the concrete should be repaired immediately upon form removal and guidance in suggested repairs are included in ACI 309.2, Identification and Control of Consolidation-Related Surface Defects in Formed Concrete.

2.4.2.2.13 Placing Moisture Barriers

Moisture barriers should be installed, applied, or affixed in accordance with the industry standards as to temperatures, number of coatings or layers, method of application, etc. Installation or coating applications should be compatible with the moisture conditions of the concrete, form removal and backfill operations, and any other operation or condition occurring concurrently with coating applications. Interior coatings should be applied only 2 feet up the walls from the floor. Any floor coatings damaged or carried away by foot or vehicle traffic should be reinstated properly before loading operations are begun. Coatings or sealers required on the bottom face of the floor should be installed as part of the floor forming system prior to concrete placement.

The type and particle shape of backfill materials and the method of placement should be considered to preserve the water-tight integrity of the moisture barrier. Sharp objects placed against the barrier could puncture or tear the surface of the applied barrier materials. A moisture barrier protector, such as impregnated fiberboard, should be considered for placement between the moisture barrier and the fill.

2.4.2.2.14 Placing Waste Packages Inside the Bunkers

Once the vault is ready to start receiving waste packages, the packages should be placed with the proper equipment and in such a manner as to produce a stable and closely stacked arrangement to minimize voids between waste packages. SRPs 4.1, 4.2 and 4.3 of NUREG-1200 should be used for applicable guidance and regulatory requirements for 1) receipt and inspection of waste, 2) handling of waste, and 3) waste disposal operations.

2.4.2.2.15 Filling Voids Around and Above Waste Packages in the Bunker

Free-draining soil fill should be placed in the voids between and immediately above waste packages within the bunker. Fill should be placed in a manner that does not damage the waste packages or the bunker, and should follow the applicable guidance in Appendix A of SRP 4.3 of NUREG-1200. Compaction of the fill is not required until the level of fill reaches an elevation that is 1 ft. higher than the top surface of the waste packages. Compaction efforts should be carefully controlled and limited to prevent damage to the waste packages or BGV. One possible method is the use of a vibratory plate attached to the boom of a backhoe-excavator that is located adjacent to but a safe distance from the excavated slope. The fill should be placed at dry or low moisture content and should be protected to prevent it from becoming saturated during operations. Fill placement may be accomplished using a crane and bucket or using a conveyor and mobile hopper system.

2.4.2.2.16 Closing and Sealing of Access Openings

Access openings that were necessary for loading of the bunker should be closed and sealed in such a time and manner consistent with scheduled waste-disposal operations and should be completed only after the need for the opening has ended. The following are recommended procedures that should be followed for closing and sealing the two types of openings.

1. Side loading. There is likely to be only one side opening to serve as access to the unit and it would be in the wall that will be completed last. Once a bunker has reached its

capacity for waste-package disposal, the opening should be prepared for closing by having the forms erected, the reinforcing steel placed and the concrete deposited. Once the concrete has reached the required strength for form removal, the forms should be removed, and the concrete cured until its 28-day strength has been achieved. The final step should be, using previously prepared grout and return ports in the top of the unit wall, the pressure grouting operations to completely finalize the void-filling procedure. The grout should be a neat portland-cement slurry grout having a unit weight of approximately 112 pounds per cubic foot and a viscosity compatible with the void system of the granular material so that the grout should percolate into and bond with only the top 6 inches of granular material and fill the remaining void space between the upper surface of granular material and top cover. Figure 2.4.2 illustrates the side loading EMCB concept.

2. Top loading. The top loading access should be closed, once the waste-package placement has been completed, by placing the required remaining granular fill material, placing and attaching the top cover, then grouting the remaining void, in the manner and with the material, as described in paragraph 1 above. Grouting would not be needed if the final compacted surface of the fill served as the foundation for a cast-in-place concrete vault roof. Figure 2.4.3 illustrates the top loading EMCB concept.

2.4.2.2.17 Placing and Compacting Fill Adjacent To the Bunker

A free draining soil layer should be placed and compacted around the sides of the bunker. Recommended procedures for selection of materials for this layer are given in Section 2.7. The lateral thickness of this layer depends on slope excavation angles required for the specific site, operating clearances required, and anticipated drainage rates and volumes. The fill should be placed and brought up evenly around the vault to minimize stress concentrations and unbalanced loads. To prevent internal erosion and piping of the overlying low-permeability cover material into the drainage layer, recommended filter criteria as discussed in Section 2.7.2.1 should be followed. Proper placement and compaction of free-draining fill is necessary to minimize settlement and recommended practice is discussed in Section 2.7.2.6. To ensure rapid drainage of any infiltrating water, the recommendations of Section 2.7.2.1 should be followed. The drainage layer placed should be designed to conduct any collected infiltrating water to the foundation drain where the flows would be collected and monitored.

2.4.2.2.18 Placement of Low Permeability Membranes

Low permeability membranes, if used, should be installed or placed on top of the completed vault in accordance with recommended

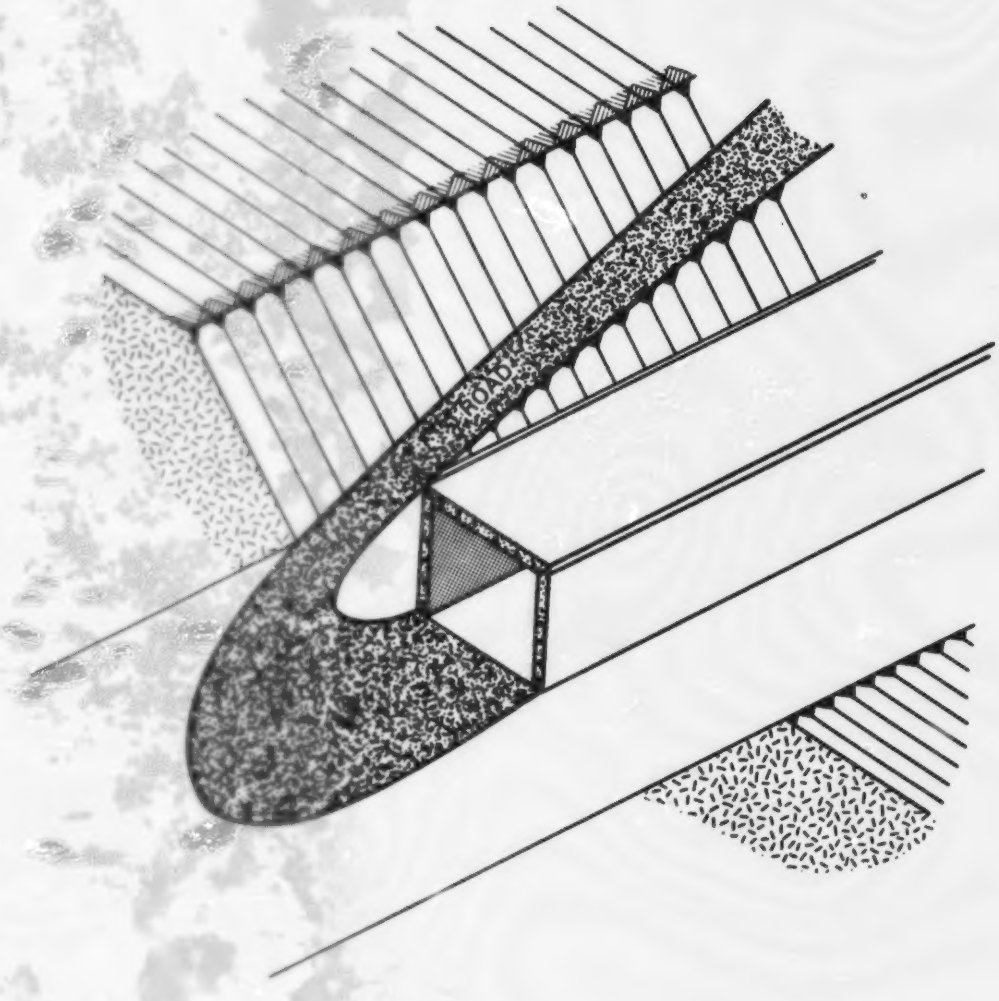

Figure 2.4.2. Side loading concept of waste emplacement in an EMCB

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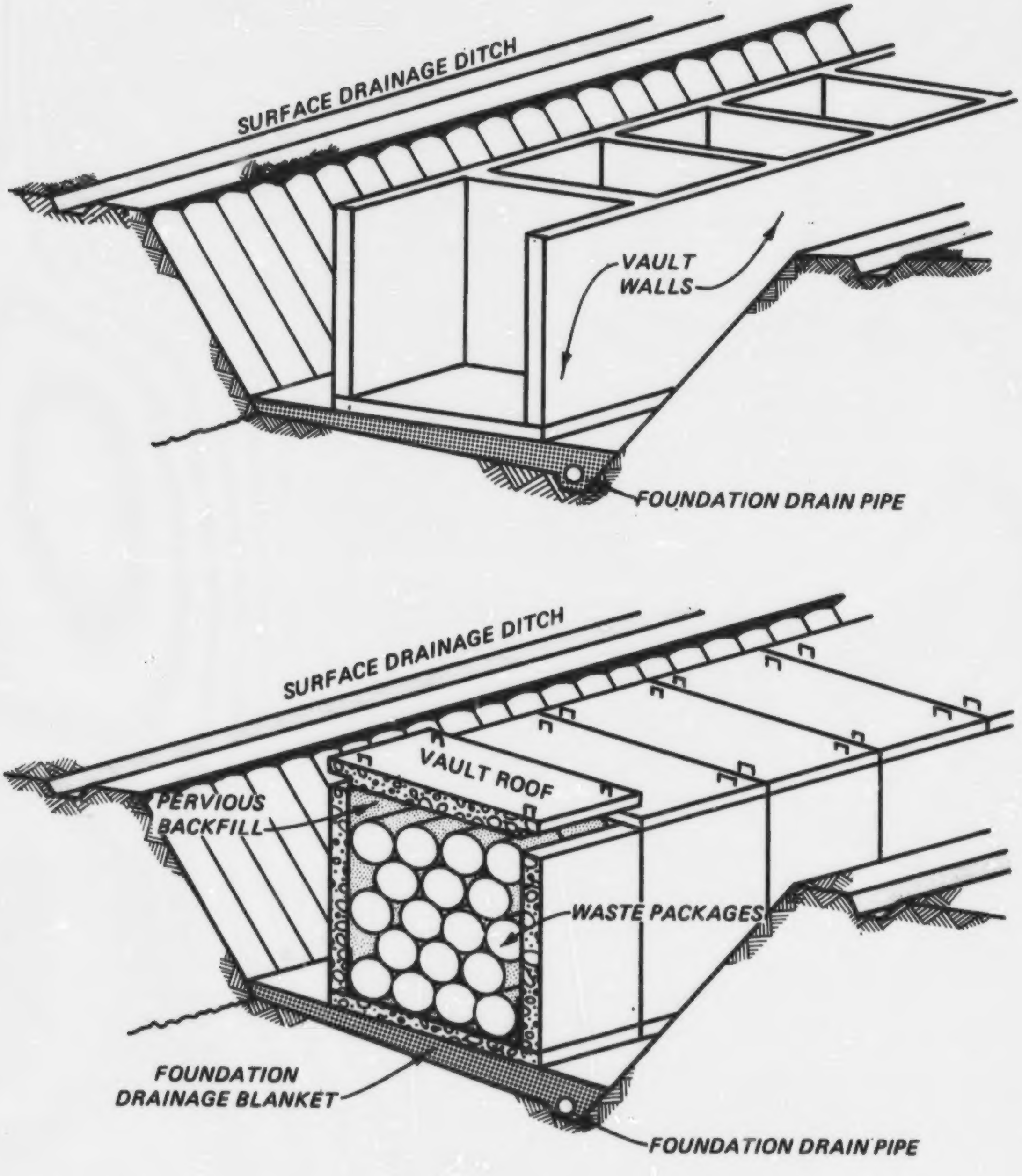
SURFACE DRAINAGE DITCH
VAULT WALLS
FOUNDATION DRAIN PIPE
SURFACE DRAINAGE DITCH
VAULT ROOF
PERVIOUS BACKFILL
WASTE PACKAGES
FOUNDATION DRAINAGE BLANKET
FOUNDATION DRAIN PIPE

Figure 2.4.3. Top loading concept of waste emplacement in an EMCB

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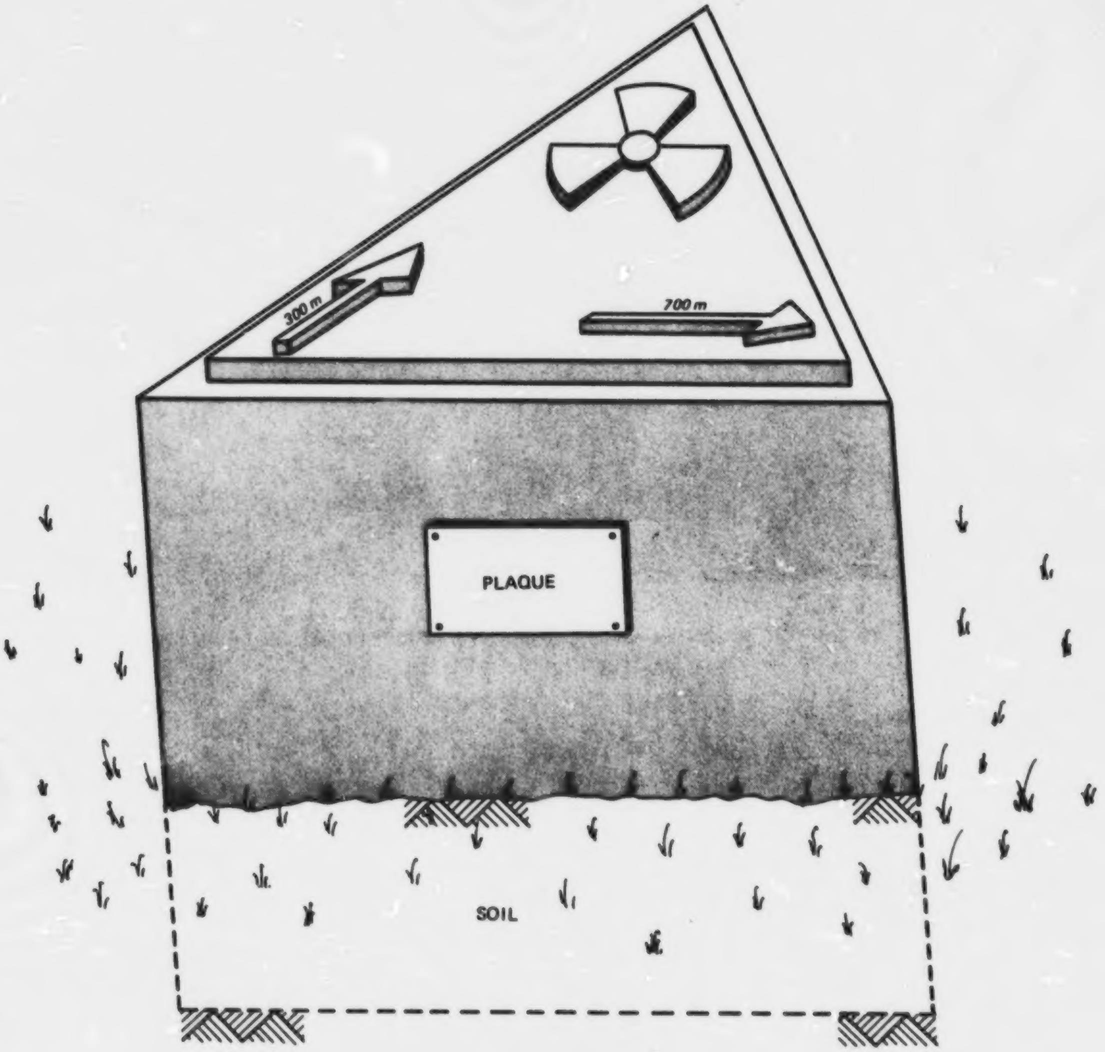
300 m
700 m
PLAQUE
SOIL

Figure 2.4.4. Example of a record monument

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46

2.4.2.4 Construction, Operations, and Closure Impacts

There are certain concurrently occurring features discussed in the following paragraphs that should be considered because of their impact on the construction efforts to build an EMCB.

2.4.2.4.1 Roads and Bridges Compatible with Equipment

Design and construction of roads and bridges for operations and access to the site should take into account the number, size, and weight of the motorized equipment to be used during construction and operations. Roads, pavements, and bridges to the site and on-site need to be adequate for the anticipated traffic.

2.4.2.4.2 Construction and Operations Sequence

The construction sequence should be planned and scheduled so that several operations can occur simultaneously with a minimum impact of one on another. For instance, construction, operation, and closure of separate disposal units may take place simultaneously, as long as construction and operations do not adversely affect the other, or the performance capabilities of closed units. Vehicular traffic, including construction equipment, should not adversely impact completed disposal units or those being constructed or operated. Regulatory evaluation criteria for auxiliary facilities, including roads and bridges, are discussed in SRP 3.4.2 of NUREG-1200.

2.4.2.4.3 Worker Safety

Worker safety should be a foremost consideration throughout the construction and operations phases. All shielding, bracing, cribbing, scaffolding, etc., should be carefully selected and installed using accepted practice and following OSHA regulations to reduce the possibility of worker injury.

2.4.2.4.4 Disposal Operations

Waste-disposal methods should be capable of providing reasonable assurance that all the Subpart C Performance Objectives and pertinent Technical Requirements of Subpart D of 10 CFR Part 61 can be met. The information and description on construction, operations, and closure will be reviewed for completeness in conjunction with guidance in NUREG-1199 and NUREG-1200. NUREG-1200 provides guidance on how the license applicant's proposed methods will be evaluated for compliance with 10 CFR Part 61 requirements.

industry standards prevalent at the time of construction. The membrane, after installation, should be protected from damage by personnel and equipment and should be repaired if necessary prior to waste package placement if damaged.

2.4.2.2.19 Placing Waste Packages in Tumuli

Waste package containers should be placed as delineated in Section 2.4.2.2.14. The packages should be placed in a stepped arrangement. Means should be provided to maintain the stack integrity during backfill operations to ensure proper waste containment and provide for worker safety.

2.4.2.2.20 Placing Pervious Backfill Between and Above Waste Packages in Tumuli

Pervious backfill material should be placed between and above the waste packages to fill voids and enhance waste isolation.

2.4.2.2.21 Constructing Low-Permeability Backfill

The low-permeability backfill layer, constructed above the pervious fill over the waste packages, should minimize infiltration of water. Guidance for design and construction of the layer is provided in SRPs 3.1, 3.2, 3.3.1, 4.3, 5.1.2, and 6.1.2 of NUREG-1200. Proper compaction of low permeability soils is essential to minimize infiltration, settlement, and subsidence. Low permeability soils require different placement and compaction methods and specifications than free-draining materials. Selection of materials and recommended practice for placement and compaction are discussed in Section 2.8.

2.4.2.2.22 Placing Rock Protection, Topsoil and Establishing Vegetation Over the Completed EMCB

Upon completion of low permeability layer construction, measures should be taken to minimize erosion. These measures include placement of a topsoil layer and establishment of vegetation and may include placement of rock protection. The topsoil layer should be a minimum of 3 feet thick so that shallow-rooted vegetation does not significantly penetrate the low permeability cover. To minimize erosion, it should be compacted, but compactive effort should be less than for the backfill layers. Shallow-rooted vegetation should then be established over the disposal unit. Table 2.8-1 shows root depths of various plant species. Tucker (NRC, 1983) provides guidance on selection of vegetation. Department of the Army Technical Manual TM-5-830-2 "Establishment of Herbaceous Ground Cover" also provides guidance on establishment of vegetation. Further guidance and recommendations are provided in Section 2.8.2.2.

2.4.2.2.23 Constructing Final Surface Drainage Features

Final surface drainage features required for EMCB disposal are essentially the same as those required for shallow land burial. Guidance is provided in SRPs 3.4.4 and 5.1.1 of NUREG-1200, and in Department of the Army Engineer Manual EM-1110-3-136, "Drainage and Erosion Control, Mobilization and Construction" (April 1987).

2.4.2.2.24 Constructing Record Monuments

The intent and primary function of a monument is to warn of danger and the prevention of inadvertent intrusion. The monument should be constructed of a durable material so that it will transmit the message to each new generation of people. The material(s) for the monument should be nonappealing for someone to take for personal use or construction purposes. The material and configuration should be such that vandals would have a difficult time impairing the message of the monument. The monument should be large or deep and strong enough so that it could not be removed. The monument should be of sufficient height so that natural deposition of soil will not cover it over the decades. A good material for the monument would be air-entrained, very dense, high-strength concrete. It could be cast in a triangle which is the international warning symbol. The monuments should be set at the corners of the disposal units. The triangle should have the radiation symbol on the top and arrows with the distance to the next corner. The symbols should be raised instead of recessed to prevent ponding of water in them. Guidance is provided in SRP 4.3 of NUREG-1200 on the information to be visible on the permanent markers of the disposal units. It should be remembered that the plaque may make an appealing souvenir and all efforts should be made to discourage its removal. Figure 2.4.4 shows how a record monument might be constructed.

2.4.2.3 Construction Equipment

Construction equipment requirements and acceptance criteria are covered in SRP 3.3.2 of NUREG-1200. Additional guidance is provided by Tucker (1983). Although specific EMCB construction tasks may differ from SLB construction, the regulatory requirements and acceptance criteria for construction equipment are unchanged.

Specifically, the construction equipment proposed to be used should be listed and described, including manufacturer's specifications, so that the capabilities of the equipment may be assessed. Storage, maintenance, replacement, and inspection procedures and schedules should be described. An equipment quality control (QC) and quality assurance (QA) program to ensure that acceptable procedures are followed should also be established and followed.

49

2.5 Quality Assurance (QA)

An application for a license to design, construct, and operate a LLW facility is required by the provisions of 10 CFR Part 61.12(j) to include a description of the quality control program to be applied to the determination of natural disposal site characteristics, and for quality control during design, construction, operation, and closure of the land disposal facility and the receipt, handling, and emplacement of waste, including audits and managerial controls. The Quality Control (QC) requirements 61.12(j) are bases for the development of a Quality Assurance (QA) Program.

For a LLW disposal facility, functions important for satisfactory performance of the facility include any activity, structure, system, or component that is required to meet the Performance Objectives of 10 CFR Part 61. Quality assurance comprises all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service. Quality assurance includes QC, which comprises those QA actions related to the physical characteristics of a material, structure, component, or system which provide a means to control the quality of the material, structure, component, or system to predetermined requirements.

2.5.1 General Design Criteria for QA on EMCB Construction

The following General Design Criteria on QA for an EMCB are provided as recommendations for a limited portion of an overall QA program related to testing of construction materials, verification, and record documentation. Specific guidance on the overall QA program is to be provided in NUREG-1293.

2.5.1.1 Testing of Construction Materials

The license applicant should perform tests required to verify that control measures are adequate to provide a product which conforms to specified material and industrial requirements. The applicant should procure the services of an industry recognized testing laboratory or establish an approved testing laboratory at the project site. A list of tests to be performed should be furnished as a part of the QA Program. The list should give the test name, specification paragraph containing the test requirements, and the personnel and laboratory responsible for each type of test.

2.5.1.1.1 Concrete

Concrete testing should include determinations of slump, air content, unit weight, unconfined compressive strength, and verification of any of the other physical properties as required by the regulatory agency. If the concrete is produced onsite, all constituent concrete materials should be tested in accordance with the applicable previously stated methods and conform to the required specifications and standards. If the concrete is produced offsite, the constituent concrete materials should be periodically verified as to compliance with the previously identified specifications and standards. If ready mixed concrete is used, it should meet ASTM C 94.

2.5.1.1.2 Steel

All steel items or materials (reinforcing, structural, other) should be sampled, tested, and certified for acceptance prior to shipment to the site. These items should be sampled and tested in accordance with the applicable methods and should conform to applicable standards and specifications.

2.5.1.1.3 Geotechnical Materials

Soils, aggregates, filters, cloths, and other geotechnical materials should be sampled and tested in accordance with the applicable methods, to verify conformance with the applicable specifications and standards.

2.5.1.1.4 Admixtures

All chemical admixtures should be sampled and tested in accordance with the applicable previously cited methods and conform to the specifications and standards.

2.5.1.1.5 Curing Compounds and Curing Membranes

Curing compounds and membranes should be sampled and tested in accordance with applicable methods and conform to the specifications and standards.

2.5.1.1.6 Water

Water for curing and mixing should be sampled and tested in accordance with applicable methods and conform to the standards and specifications. In general, potable water, for human consumption, should be acceptable without the need of sampling and testing.

2.5.1.1.7 Moisture Barriers

Coatings, membranes, and joint materials should be sampled and tested in accordance with applicable methods and should conform to the standards and specifications.

2.5.1.2 Verification

The applicant should perform the following activities and record the following information and data:

a. Verification efforts demonstrating that testing procedures comply with applicable requirements.

51

b. Verification that acceptable facilities and testing equipment are available and comply with testing standards.

c. Calibration of test equipment and instruments against certified standards.

d. Verification that recording forms, including all of the test documentation requirements, have been prepared.

2.5.1.3 Documentation

The applicant should maintain current records of quality control operations, activities, and tests performed on construction materials including the work of suppliers and subcontractors. These records should be on an acceptable form and include a description of the trades working on the project, the number of personnel working, the weather conditions encountered, any delays encountered, and acknowledgment of deficiencies noted along with the corrective actions taken on current and previous deficiencies. In addition, these records should include factual documentation that required activities or tests have been performed, including but not limited to the following:

a. Type and number of control activities and tests involved.

b. Results of control activities or tests.

c. Nature of defects, causes for rejection, etc.

d. Proposed remedial action.

e. Corrective actions taken.

Documentation records should cover both conforming and defective or deficient features and should include a statement that supplies and materials incorporated in the work comply as required. Legible copies of these records should be furnished daily to the responsible person(s) on the QC staff.

2.5.2 Specific Construction Inspection Criteria

The recommendations for specific construction inspection are presented for formwork, steel, and concrete operations. Recommendations for the inspection of operations to construct the tumulus portion of the EMCB are not presented in this section, but waste placement and earthwork activities (placement and compaction of both pervious and low-permeability fill) would be similar to the operations described in Sections 2.7 and 2.8 of this report and SRP 4.3 of NUREG-1200. The specific criteria presented here are intended as guidance and are not necessarily all-inclusive.

2.5.2.1 Formwork

Forms should be constructed in a workmanship manner consistent with acceptable industry standards, of materials that will successfully sustain the imposed loads by the plastic concrete and which also will impart to the hardened concrete the required finish on all formed faces. The forms should be well braced or otherwise supported to prevent sagging or collapse and provide for worker safety. The form faces should be cleaned and oiled and free of undesirable indentions prior to concrete placement. The design and construction of forms should be accompanied by a well established forms inspection program for before, during, and after concrete placement efforts (see Appendix A for a suggested form inspection program and report).

Forms should be removed from the hardened concrete in a manner that will insure that no damage is inflicted on the forms nor the concrete. If the forms are to be reused, they should be cleaned, oiled, and stored in a manner that will provide for protection from the weather and will insure that no warpage will occur.

2.5.2.2 Steel - Reinforcement and Embedded Items

All reinforcing steel and steel embedded items should be of the proper grade and should be so identified by proper markings on the steel and be accompanied by verification documentation.

Reinforcing steel should be properly installed by being tied, braced, or otherwise attached so that it will remain in the desired location during concrete placement operations, including construction/consolidation efforts. Care should be taken not to damage the epoxy coating on the steel by the installation activities. The vibrator should not be placed on the reinforcing steel since this action tends to segregate the concrete adjacent to the bars and weaken the bond between the concrete and steel.

All embedded steel should be installed in a manner that will assure that the steel will remain in the desired location during concrete placement and consolidation efforts. Care should be taken to assure that the coating on the steel items is not damaged nor impaired thereby rendering it unsuitable for use. All steel reinforcing and embedded items should be clean and free of any substance deleterious to good bonding.

2.5.2.3 Concrete Operations

This section covers:

1. the batching, mixing, and hauling of the concrete.
2. the placing and consolidating of the concrete.
3. the finishing and curing of the concrete.

The concrete batch plant should be calibrated and certified prior to the production of concrete for placement at a given LLW disposal facility. Once certification has been achieved, the batching operations should be performed in such a manner as to consistently produce the required plastic concrete having the required properties such as proper slump, air-content, unit weight, etc. A written record (such as a strip chart) should be obtained for each batch or, as an alternative, a QA representative should make visual observations of the batching operations and certify in writing that each batch has been properly measured. The mixing operation should be performed in a manner that will assure that the concrete will be mixed thoroughly to produce a uniform mixture, for the required amount of time, either in the batch plant control mixer or the ready mix trucks. If truck mixing is used, the QA representative should assure, and record, that the truck drum rotates at the proper revolutions for the required time. The hauling portion should be conducted in a manner, with the appropriate equipment, that will assure that the concrete will not segregate nor suffer a significant slump-loss in transient.

The concrete should be placed in its final disposition in the forms in such a manner that assures that the concrete will not be adversely affected by the operations. The discharge height of the concrete should be held to a maximum of five feet, whether free-falling or tremied, to avoid segregation. The practice of "moving" the concrete, once it is in the forms, by use of vibrators instead of shovels and rakes, should be avoided to guard against over-vibration and segregation. The concrete placement rate should be consistent with job site conditions such as slump and temperature. The placement rate should be such that no cold joints will be allowed to form. Vibration/consolidation operations should be performed in such a manner that will assure that the concrete will be properly consolidated, without void or honeycomb spaces, and will also guard against segregation caused by over-vibration.

The concrete should be finished, as required, in such a manner that will assure that the hardened concrete will be of the required lines and grades and will meet the job requirements for smoothness and surface-density.

The concrete should be cured by the job-required technique in such a manner that will assure that no defects will result, such as surface checks, drying shrinkage cracks, "alligator" cracks, localized loss of surface smoothness, or any other "loss-of-moisture" defect. The curing technique should be continued for the required length of time, especially if form-removal is permitted prior to cessation of curing. The QA representative should observe and record on a daily basis the status of the curing, its continuity, and any remedial action taken to keep the curing operation in compliance with the requirements.

In the event remedial repair action is required to correct defects in the vault concrete, the QA representative should survey the defect and present a corrective plan of action to the proper regulatory agency. The plan should contain but not be limited to the following information: cause of defect; extent of defect; remedial action required to repair the defect; remedial action required to prohibit reoccurrence of defect; estimated cost of repairs; and, when repair will begin and length of time to complete.

2.6 Structural Performance Monitoring

Structural performance monitoring is recommended to verify design assumptions and satisfactory performance. The monitoring program should be carefully planned and implemented, and results should be evaluated at an established reasonable frequency. A monitoring program is of little value if the data are not properly obtained and evaluated. In this section, the monitoring recommendations for an EMCB disposal unit are addressed in terms of specific criteria for:

1. Types of measurements
2. Selection of instruments
3. Special considerations
4. Limiting values of monitored parameters
5. Remedial action plan
6. Periodic inspections

2.6.1 General Criteria for Structural Performance Monitoring

Structural performance of important elements and features should be monitored, tested, and evaluated at suitable frequencies and locations and for a suitable duration to verify design assumptions and to provide reasonable assurance that the Performance Objectives of Subpart C of 10 CFR Part 61 are met. Such monitoring should be performed during the construction and operations phases and into the institutional control period, for a period of time necessary to demonstrate acceptable structural performance.

2.6.2 Specific Design Review Criteria for Structural Performance Monitoring

2.6.2.1 Types of Measurements

The types of measurements required for performance monitoring are those necessary to verify design assumptions, evaluate structural performance and stability and to assess whether 10 CFR Part 61 Performance Objectives are met. Basic parameters to be monitored for direct verification of design assumptions and evaluation of performance include loads, monitoring wells, settlements, joints, and strains experienced by the EMCB disposal unit and its components. Guidance on environmental monitoring and surveillance that is required to assure that specified exposure limits are not exceeded and that 10 CFR Part 61 Performance Objectives are met is covered in NUREG-1200 and is beyond the scope of this report. Parameters related to structural performance that should be monitored include drain sump-water levels and flow quantities and ground-water levels.

It is recommended that the monitoring of certain essential parameters be performed at each site. Essential monitoring would measure liquid levels and flow qualities that may collect in the drains and sumps by use of monitoring wells; movement (strains) at anticipated locations of maximum stress within the vault members by use of strain gages; total and differential settlement of the EMCB by use of settlement gages; and measurement of joint movement by the use of strategically

56

placed strain meters across key joints within the structure. Detection of liquid levels in monitoring wells could indicate the presence of infiltration or ground-water rise or a loss in water tightness of the vault. The measurement of strains in key members of the bunker could provide a means of assessing and monitoring loads and stresses applied to the structure in comparison to design estimates, as well as providing a system that will warn of excessive strain. Gages or meters across key strategic joints could warn of excessive movement within areas of the bunker and also predict possible paths of liquid seepage if the movements continue. The monitoring of lateral, vertical, and horizontal movement of the EMCB could be recorded by the use of settlement gages, reflecting both total and differential settlement or lateral movement.

It is further recommended that other parameters be considered for optional monitoring to project long-term structural behavior and early warning of the possible development of adverse conditions. Optional monitoring could include the measurement of stresses within the structural members of the bunker; measurement of deflections within the structure (of key structural members); and, measurement of pore pressure within the concrete and the soil surrounding the bunker. The measurement of stress could be obtained at certain key locations to monitor stress response of the vault. The measurement of deflections could help present the status as to the allowable deflections in vault members in response to externally applied stresses. The status of the pore pressure in the concrete and soil would add to the knowledge of the structural integrity of the total engineered structure.

The scope, extent, and duration of monitoring of structural loads, strains, stresses, deflections, and settlements of the EMCB should be based on the results of the technical analyses (10 CFR 61.13), the results and evaluations of initial monitoring efforts, and the importance of these parameters in demonstrating that the Performance Objectives are met.

2.6.2.2 Instrument Selection

The selection of instruments should be based on demonstrated reliability and durability of the instruments. Simple, robust, mechanical instruments and devices are preferred over complex, electronic, sensitive devices for reliable long-term monitoring. Electronic instruments should not be prohibited or discouraged, but it should be recognized that the service life of individual instruments is limited. However, the instruments discussed in this section have generally been shown through experience to be durable and long-lived. It may be impractical or impossible to repair or replace some of the installed instruments as they cease to function. Therefore, the goal of monitoring should be to establish a data base during the construction, operations, and closure phase, and into the active institutional control period, from which to verify design assumptions and to be able to reliably forecast long-term performance.

57

The monitoring plan submitted by the license applicant should provide estimates of instrument service life and describe actions to be taken in the event that instruments fail or when measured parameter values exceed established limiting values. Sections 2.6.2.7 and 2.6.2.8 provide guidance for establishing limiting values and a remedial action plan. The effects of instrument failures on the reliability of site and structure performance evaluations should be discussed and evaluated in the supporting documents for a license application. The effects of design basis events on instruments should be assessed and reported. All monitoring instruments should be calibrated and installed by qualified, experienced personnel using accepted methods. Instrumentation and devices appropriate for monitoring EMCB's are discussed in the following paragraphs.

2.6.2.3 Monitoring Wells

Monitoring wells are considered essential and should be strategically placed near the disposal units to measure levels and flows of liquids collected in the drains and sumps for the EMCB and those in the foundation drains. Monitoring wells placed in drain sumps provide the best means for determining effluent quantities and character from individual disposal units. The wells should be of sufficient diameter to allow water samples to be taken and should be capable of being pumped or bailed, if necessary, for removal of effluent. The sampling frequency should allow for early detection of contamination and treatment, before offsite discharge could occur. The philosophy for establishing sample intervals should be to prevent significant changes in quantity or quality of effluent from going unnoticed. This requirement implies a sampling interval shorter than the estimated travel time and required response time for remedial action. Wells should be designed to last many years with minimal maintenance at the intended frequency of sampling.

2.6.2.3.1 Well Design

Design for monitoring wells should be presented in detail and should include installation and construction methods as well as engineering and material features.

2.6.2.3.1.1 Casing

Specifications for water-well casing should designate ASTM A 120 or ASTM A 53. American Petroleum Institute (API) casing is designated by the outside diameter and the wall thickness.

The size of the casing should be designed to ensure that bailer, pump, and other necessary equipment can be inserted. An inside diameter of about 6 in. is reasonable, but only the strength of the casing limits sizes much larger. For structural reasons, the diameters of plastic well casings are usually not larger than 6 in.

The diameter of the casing should be sufficient to admit sampling devices (e.g., bailer or pump) or geophysical logging instruments. Pumping by air lift is not recommended for sampling those constituents that are susceptible to oxidation by air or are volatile. Casing should be considered on the basis of its durability and resistance to corrosion and chemical attack. Heavy-duty PVC (Schedule 80) or stainless steel pipe should be used for well casing for monitoring EMCB drain sumps. Stainless steel pipe is resistant to corrosion and is less likely to be damaged by any required well cleaning or maintenance operations. The composition of the casing material affects some geophysical measurements to a greater degree than others. For example, casings of PVC or other hydrogen-containing materials attenuate the signal for moisture content when neutron logging tools are used, while porosity measurements are relatively unaffected by the PVC casing. Metal casings are better for neutron logging for soil moisture content, but sensitivity is decreased when making natural gamma-ray measurements through metal casings. A complete discussion of this topic is given by Keys and MacCary (1971). Epoxy plastic pipe has a high resistance to corrosion and incrustation.

Casing and screens should be washed with a detergent, rinsed with clean water, and protected from contamination prior to installation.

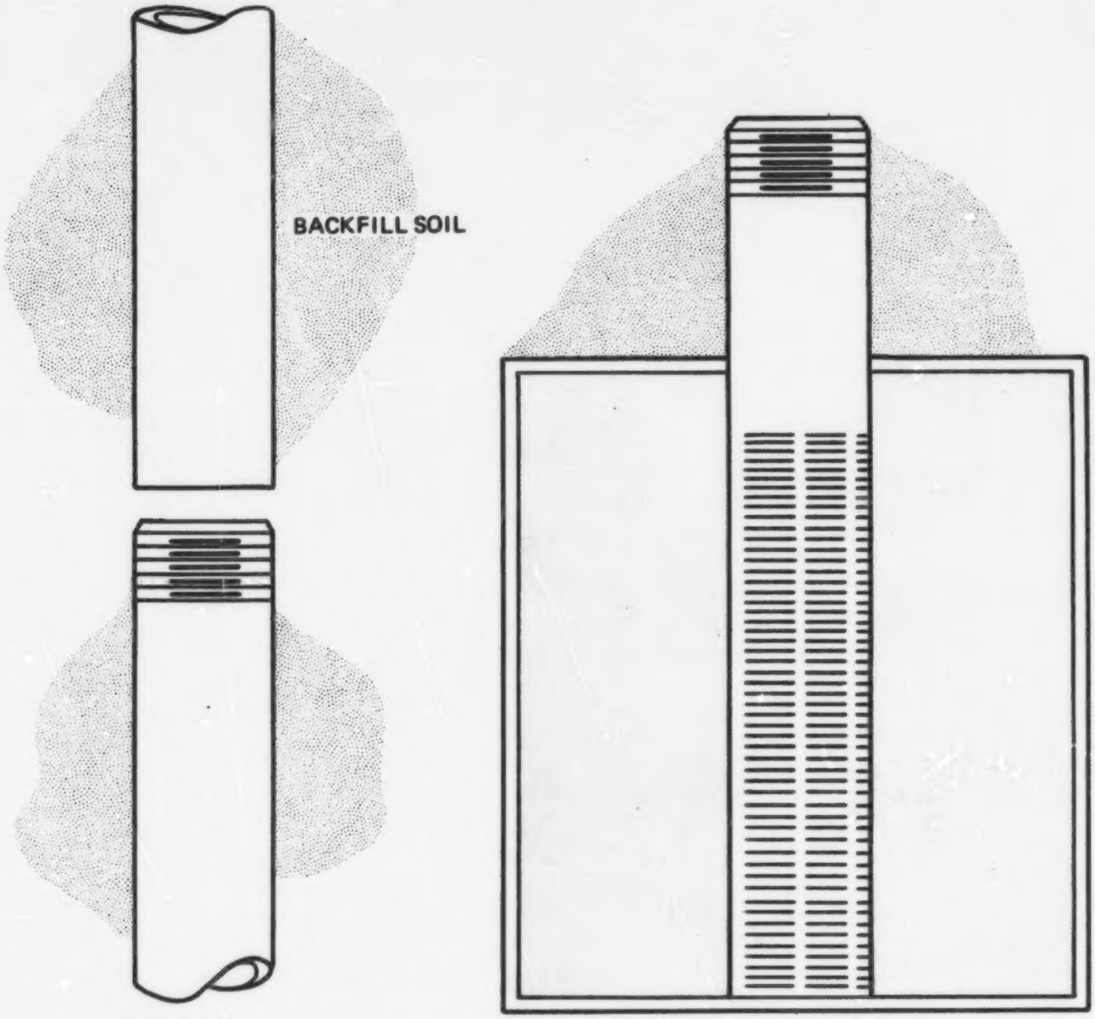
2.6.2.3.1.2 Joints and Seals

The casing must be positively sealed to prevent mixing of water from inside and outside the casing and sump. Sealing is best accomplished by properly compacting backfill around the casing and by use of tight joints. Threaded joints may be preferred. A collar surrounding the casing at the upper surface of the low-permeability layer may be useful for directing water away from the casing and low-permeability soil interface and into the drainage blanket. The collar material should be durable and should tightly seal around the casing. The use of seepage collars around the well casing could be considered as a measure to prevent liquids from vertically seeping along the outer casing.

PVC cements may bleed organic constituents and may also pose adsorption problems that can affect the quality of the sampled water. In this case, uncemented threaded sections of PVC pipe should be used (Figure 2.6.1) and made watertight with a manufacturer approved joint compound.

2.6.2.3.1.3 Screen

Factors that influence the selection of materials for screens for monitoring wells include strength requirements, water quality, and the potential presence of iron bacteria. The intake screen portion of a monitoring well should be properly



RISER WITH JOINT
(OVERLAPPING DOWN)

SCREEN IN SUMP
(SCHEMATIC SECTION)

Figure 2.6.1. Features of sump monitoring wells

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designed, constructed, and developed to avoid subsequent sampling problems. For an intake in an open sump, the screen can have large openings since the small amount of sediment there can be removed with the water sample. In contrast, a screen embedded in sand in the collector drain of the foundation functions differently. It is necessary that the screen openings be small enough to keep the surrounding sediment out. Suitable well screen materials include wire-wrapped stainless steel, slotted thermoplastic, and fiberglass. Thermoplastic and fiberglass screens are highly resistant to corrosion but are as susceptible to encrustation as metal screens. Guidance on selection of well screens is given by Driscoll (1986).

2.6.2.3.1.4 Soil Backfill

Soil backfilled around the riser casing provides structural stability when properly placed and compacted. Backfill adjacent to wells is contiguous with and should be composed of essentially the same materials as the free-draining backfill surrounding the EMCB and the low-permeability and topsoil layers where the well passes through these layers (Section 2.4.2.2.17) except that special methods of construction are required for the different types of materials. Placement and compaction of soil adjacent to the riser should be accomplished by hand-operated tamper and with considerable care. Density should approach that achieved with heavy equipment elsewhere in the backfill, at a distance from the well where heavy equipment compaction is possible. Guidance for placement and compaction of free-draining fill, low-permeability fill, and topsoil are given in Sections 2.7 and 2.8.

2.6.2.3.2 Maintenance of Wells

Monitoring wells should be cleaned and developed upon installation and subsequently during periodic maintenance. Corrosion of screens or casing, bacteriological clogging, and deposits of dissolved minerals (calcium carbonate, ferric hydroxide, and other materials) are common problems that may contribute to failure of a well. Corrosion may be minimized by installing corrosion-resistant screens as discussed above and can be reduced by providing cathodic protection if metal screens are used. Steam cleaning is an effective physical means to reduce clogging and encrustation. Chemical treatment to remove bacteriological clogging of monitoring wells is effective. For example, a strong chlorine solution is effective in controlling iron bacteria. Acid is effective in dissolving precipitated iron and manganese. However, use of acids and other chemicals may have disadvantages such as masking monitoring and testing results. Such potential disadvantages should be considered. When iron bacteria are known to exist, screens should be selected that can withstand repeated chemical treatments.

Any method proposed as a means of cleaning should be considered carefully as a potential source of influent into the drainage system. Steam cleaning may offer an advantage in this regard.

Driscoll (1986) provides additional guidance on well maintenance. All practices proposed for well maintenance should be shown to have no lasting adverse effects on monitoring capabilities of the well.

2.6.2.3.3 Sampling and Observations

Criteria are not provided herein on routine sampling and observations. Acceptable methods of water sampling and sample handling and preservation procedures are contained in documents by the American Public Health Association (APHA 1980) and the US Environmental Protection Agency (USEPA 1979 a and b) and Techniques of Water Resources Investigation of the United States Geological Survey (Brown, Skougstad, and Fishman 1970). These procedures should be considered when developing monitoring plans.

2.6.2.4 Structure Monitoring

As previously stated in Section 2.6.2.1, the scope, extent, and duration of monitoring of this type should be based on the results of technical analyses, the results of initial monitoring efforts, and on its importance in demonstrating fulfillment of 10 CFR Part 61 Subpart C Performance Objectives. Satisfactory short-term results have been achieved with the types of instruments discussed in the following paragraphs; however, specific applications, locations, or gage size may dictate use of one over the other. No known monitoring devices or instruments can be expected to last indefinitely. Therefore, the potential consequences of failure, replacement, or abandonment must be considered in planning the program.

2.6.2.4.1 Strains

Strain measurements are considered to be essential and should be made in a bunker to assess the stresses that develop in corresponding parts of the structure. Several types of gages, e.g. Carlson strain meters, vibrating wire strain gages, and Carlson R-C (reinforced concrete) meters can be used to make relatively long-term strain measurements in concrete or reinforcement. Short-term measurements can be made with various embedment gages, e.g., Ailtech embedable strain gages and strain-gaged rebars. The Carlson strain meter and the vibrating wire strain meter have sensitivities of 1.5 to 3.6 and 1 micron strains, respectively. The applicant should provide the basis for selection of gage types.

2.6.2.4.2 Stress

Stress measurements are considered optional, but if they are used, they should be made in concrete or reinforcement in a bunker to determine the final equilibrium conditions and their interactions. Relatively long-term stress measurements should be made with Carlson stress meters while short-term measurements can be made with strain-gaged diaphragm stress meters. Sensitivity of the Carlson stress meter is 3 to 10 psi, depending on the gage selected.

2.6.2.4.3 Deflections

Deflection measurements of a concrete structure are considered to be optional, but if used, they should be made to determine the load deformation characteristics. Two general methods available include: (1) internal measurements through observation of a plumbline and (2) external measurements through observations by geodetic triangulation on external targets attached to the structure.

Deflections of the vault roof should be measured to verify its structural integrity. Criteria governing allowable deflections are provided in Ch. 9, Table 9.5.a of ACI 349-85. Further guidance is given in Section 2.6.2.7 of this report.

To determine roof deflections, a simple and reliable device of suitable durability for long-term monitoring is needed. A single-point rod extensometer would be acceptable. An extensometer consists of a rod connected to an anchor or plate that is securely attached to the vault roof. The rod extends to a reference head at the ground surface that is anchored by grouting. The rod must be placed in a protective casing to prevent frictional resistance to movement by the surrounding soil material. Measurements of the rod's position relative to the reference head can be made manually by dial gauge or depth micrometer or remotely by an electrical transducer or sonic probe. Several instruments should be installed to monitor points on the vault roof corresponding to the centers of main spans.

The elevations of the reference heads should be determined so that any settlement of the ground cover is distinguishable from roof deflections. This can be accomplished by surveying to a vertical precision of 0.1 in., which can be done with a 1-sec. vertical angle reading theodolite from a remote position located on stable ground. The use of a "Total Station" incorporating both the above theodolite and an electronic distance measuring instrument accurate to better than ± 5mm + 5ppm is desirable. Measurement stations should consist of concrete pillars or steel pipes embedded in concrete in the ground. Targets should be similarly embedded.

63

2.6.2.4.4 Settlements

Settlement of the vault foundation and tumulus portion is considered very essential and should be monitored to detect any potentially unsafe conditions before structural distress occurs. Monitoring should be conducted both during and after construction and waste disposal operations. The monitoring records should clearly record the status of applied loading for future correlation and evaluation of settlement records.

Criteria governing allowable total and differential settlements should be established based on design assumptions and allowable limits. Sowers (1979) gives examples of allowable settlements for various structures. For example, the maximum allowable differential settlement for a reinforced-concrete building frame is 0.0025 to 0.004L, where L is the distance between 2 points that are settling differently.

An optional settlement profile of the in situ soil could be obtained during construction using horizontal inclinometers. The inclinometer casing should be installed horizontally in the soil prior to construction. The sensor is pulled through the casing by means of a cable. Measurements of angular deformation from the horizontal are taken at successive intervals along the length of the casing. The vertical settlement is computed from the sine of the measured angle.

Possible limitations of this system are that bending of the casing may render it unusable if the sensor can no longer pass through it. The system also has a limited length since the total settlement of an interval is obtained by summation of the settlements of the preceding intervals. The profile lines may need to be aligned across the width of the vault. Finally, the system may not prove feasible for long-term monitoring since it may not be desirable to maintain access to the open end of the casing. It would, nevertheless, give valuable information on settlements beneath the vault for the period of time when most settlements are expected to occur.

The settlement of the underdrainage blanket, and those portions of the in situ soil not covered by the profile lines, may be obtained, if desired, using settlement probes. These devices may also be used for long-term monitoring since its life is only dependent on the durability of the casing.

This measurement system essentially consists of a measuring probe and plastic well casing with telescoping couplings. Measurement stations should be established around the periphery of the vault such that the casing may be installed as close as practicable to the walls. The probe can either be a mechanical device that latches to the bottom of each section of casing or an electrical device that senses the position of metal rings attached to the casing. Elevations are determined by a graduated tape or cable. The elevations of the casing tops may be determined by surveying in the same manner as discussed for deflection monitoring.

2.6.2.4.5 Joints

Contraction joints in concrete structures open and close with decreasing and increasing temperature and it is considered essential that this movement be monitored with strategically placed meters or gages. Opening and closing of joints could potentially lead to seepage of fluids into the structure and eventual escape of radioactive waste constituents into the surrounding soil. Joints can be monitored electrically with Carlson joint meters. Meters can be installed that will measure joint openings to 0.4 in. wide. The least reading of the joint meters varies from 0.0002 in. to 0.001 in. depending upon the joint meter selected.

2.6.2.4.6 Pore Pressures

The optional measurement of pore pressure could provide more information as to the stability of a bunker as it is affected by water pressure in the foundation material and in the pores and joints of the concrete. In measuring the pore pressure in the concrete, a device should be used which requires practically no flow of water. A device which has been found suitable for measuring pore pressures in concrete is the Carlson pore pressure cell. This cell is similar to the Carlson stress meter except that the water under pressure filters through a porous stone and deflects the elastic diaphragm whose movement is measured electrically. This device can also be used in foundations where leakage is expected to be small. The Carlson pore pressure cell has a sensitivity of 0.1 to 0.8 psi depending on the gage selected. These gages have performed continuously for 10 years at one Corps of Engineers project site.

2.6.2.5 Data Acquisition Systems

Most electronic sensors and gages can be monitored with portable instruments. Frequency of measurements should be determined by the quantity of data required to establish an effective data base and by the estimated consequences of potential changes between readings. A more regimented collection of data can be accomplished with a remote microprocessor based data acquisition system scheduled for specified collection times. A remote system can be battery powered with solar panel charging systems. Optional methods of data transmission are: (1) telephone lines via modem; and (2) telemetry via GOES satellite.

2.6.2.6 Special Considerations and Requirements for Meters Embedded in Concrete

2.6.2.6.1 Inhomogeneity of Concrete

Concrete is a heterogeneous substance consisting of aggregates of various sizes and of various types, hardened cement paste, voids, and water in different states of chemical and physical bonding. Local strains and stresses can and will vary extremely. In such a material, any strain meter installed should have a length at least two to three times the maximum aggregate dimension. Stress meters should have a cross-sectional diameter of three to four times the maximum aggregate dimension.

2.6.2.6.2 Shrinkage and Swelling

The range of the embedded meter must be large enough to allow measurement of strains or stresses due to shrinkage and swelling as well as those due to loads. Measures must be taken to facilitate the separation of the two types of strains or stresses.

2.6.2.6.3 Temperature

Meters embedded in any structure should remain operable during and after exposure to the maximum credible anticipated temperature range.

2.6.2.6.4 Moisture and Corrosion

The meters and wiring must be unaffected by water, which may be under fairly high pressures and contain various aggressive agents.

2.6.2.6.5 Measuring Range and Resolution

In general, a total strain range of +500 to -1,000 microstrains or a stress range of +600 to about -3,000 psi is usually satisfactory. The resolution and accuracy of meters should preferably stay within a range of only a few microstrains or psi.

2.6.2.6.6 Placement and Orientation

The position and orientation of the meter within the concrete body must be precisely known. Therefore, prevention of any shift or tilting of the meter during the placement and consolidation of the concrete is important. Meters and wire connections must be rugged enough to safely withstand the rough placement and compaction procedures. Conduct for the passage of instrumentation cable bundles through any portion of the concrete vault should be firmly anchored and made water-tight by some means such as expansive portland cement grouts or epoxy grouts.

2.6.2.6.7 Long-Term Stability and Reliability

One of the greatest problems with embedded meters is that of ensuring their long-term stability to obtain reliable and accurate observations over long periods of time. The main threats to the reliability of meters are moisture effects, corrosion, and creep or volume change within some parts of the meter itself. Meters should be selected that have a past history of satisfactory long-term use in concrete structures.

2.6.2.7 Limiting Values of Monitored Parameters

Limiting values should be established for those parameters related to verification of structural design assumptions, assessment of performance, assurance of safety, and satisfaction of the Performance Objectives of Subpart C of 10 CFR Part 61. These limiting values or action levels should be determined and established using appropriate regulations, codes, standards, and accepted engineering practice. Limiting values required for verification of structural design assumptions and assessment of structural performance include loads, stresses, deformations, and strains experienced by the structure, systems, and components and the foundation, backfill, and cover system. Limiting values required for the assessment of structural performance include the amount and quality of the water flows and levels in drain sump and monitoring wells, ground-water levels, and soil moisture contents. Limiting values required for verification of structural design assumptions and assessment of structural performance are recommended in the following paragraphs. These limiting values do not necessarily indicate failure. Rather, they are values that should indicate a need for decision-making and response. Appropriate responses may include no action, increased monitoring, or remedial actions.

2.6.2.7.1 Limits on Structural Deflections

Control of deflections of reinforced concrete structures are specified by ACI 349-85, Section 9.5. Maximum permissible deflections for typical reinforced concrete members are listed in Table 9.5(a) of the ACI publication. Guidance is also provided in the code and corresponding sections of the commentary for calculating and controlling deflections. The limits in ACI 349-85 should be the basis for establishing the limiting values of structural deflections.

The actual deflections in the structure should be monitored to determine if any member or component is approaching the deflection limit. Where the limiting deflections based on ACI 349-85 would produce strains greater than 0.002 in/in. for concrete or 0.0015 in/in. for steel, the deflections that correspond to these strains should be used for monitoring.

If the actual measured deflection or strain approaches the limiting value, then remedial action must be considered such as removing or reducing loads or strengthening the structure. The member can be strengthened by the addition of more reinforcement and concrete or by pumping grout under sections that might need additional support.

2.6.2.7.2 Limits of Strain for Reinforced Concrete and Steel Reinforcing

The limiting values for strain should be the values associated with the limiting deflections. The limiting strain for each element (beam, slab, wall) can be obtained by (1) calculating the stress associated with the limiting deflection, and (2) using the elastic stress-strain relationship. The maximum usable strain for concrete is assumed to be 0.003 in/in. and the yield strain for steel is assumed to be 0.002 in/in.

The limiting strain values will vary according to the span, modulus of elasticity, moment of inertia, support conditions, and the maximum permissible deflection. However, if the strains so calculated exceed 2/3 of the maximum usable strain for concrete, i.e. 0.002 in/in., or 3/4 of the yield strain for steel, i.e. 0.0015 in/in., then the latter values should be used for monitoring. A table of limiting strain values and their locations should be prepared for reference when establishing monitoring requirements.

2.6.2.7.3 Limits for Structural Loads

Structural loads and stresses are discussed in Section 2.2 "Structural Design and Analysis." Section 2.1.2.3 of this report specifies load combinations to be used for calculation of required strengths to resist anticipated loads. ACI 349-85, Sections 9.3 and 9.4 provide guidance on strength design. If measured loads exceed the unfactored loads used to calculate required strengths using the appropriate strength reduction factor, then the measured loads should be considered excessive. That is, if L measured is greater than L Design, or D measured is greater than D Design, the measured loads are excessive and appropriate response must be considered, as discussed in Section 2.6.2.7.

2.6.2.7.4 Limits for Soil Deformations and Strains

No standards or codes exist for determining allowable deformations of soil masses. However, guidance has been developed for most common forms of problems, such as tolerable total and differential settlements for different classes of buildings and other structures. Existing guidelines are based primarily on observations of full-scale structures subjected to construction, operation, and normal service loads.

2.6.2.7.4.1 Differential Settlements

Department of the Navy NAVFAC DM-7, Chapter 6, Table 6-1 and Sowers (1979) list tolerable differential settlements for several types of structures, in terms of settlement profile slopes. For example, the maximum tolerable differential settlement of overhead crane rails is 0.003 radians. This value would correspond to a differential settlement of 3/4 in. in a 20-ft distance along the crane rail. These values should serve as guidance in establishing limiting values for differential settlement, but are not necessarily absolute limits. If calculated or measured settlements approach these values, the licensee should evaluate their effects on structural loads and stresses. Methods are available in design to reduce anticipated differential settlements and their effects. For example, a common method for reducing differential settlements is to use stiff mat foundations or to accelerate consolidation rates prior to construction. To reduce the effects of differential settlements, the structure may be designed in some cases to accommodate the large expected movements.

2.6.2.7.4.2 Total Settlements

Uniform settlement of a structure, even if relatively large, seldom causes damage to a structure. Rather, differential settlements are the primary cause of damage. Total settlements are normally limited to ensure that differential settlements are kept small. However, very large (greater than 3 to 4 in.) total settlements could cause damage to the structure, especially where drain lines or access openings occur. Such large settlements could also cause cracking and subsidence of the low-permeability cover over the waste, and partial or complete loss of effectiveness of the drainage layer. Therefore, large total settlements should be avoided. Foundation settlements can be reduced through a variety of methods, such as surcharging soft soil deposits prior to construction, compacting such deposits, and removal of unsuitable soils and replacement with better quality and competent soils. Earth-mounded concrete structures, by their very nature, take advantage of one commonly used method to reduce total settlements. That is, the structure and its contents would have approximately the same mass as the excavated soil volume. The additional foundation loads are quite small, which should result in small settlements.

Total and differential settlements of the EMCB can be controlled and minimized by careful selection, placement, and compaction of the fill, drainage, and cover layers, as discussed in Sections 2.7 and 2.8.

Guidance for establishing limiting values for total and differential settlements may be found in several soil mechanics textbooks, e.g. Peck, Hansen, and Thornburn, (1974); Terzaghi and Peck, (1967); Lamb & Whitman, (1969); Winterkorn and Fang (1975);

and Sowers, (1979), as well as in NAVFAC DM-7, and Army Engineer Manual EM-1110-2-1904, (Jan 1953).

2.6.2.7.4.3 Lateral Deformations

Lateral deformations in soil masses occur when confining or applied pressures change. Excavation for vault construction, stockpiling excavated soil near the excavation or a completed vault, and backfill compaction are the primary mechanisms that would cause lateral deformation. Lateral deformations may have beneficial as well as undesirable effects. As backfill is placed and compacted the vault walls may deflect slightly inward. The backfill moves with the wall, soil shear strength is mobilized, and lateral earth pressures decrease as a beneficial result. Undesirable effects might include lateral deformations of the natural soil of the excavation walls that result in settlements of the ground surface adjacent to the excavation. If proper design and construction procedures are followed, lateral deformations are not expected to cause problems. Since the main cause of concern would be soil settlement over completed units adjacent to excavations for new units, limits on settlement are more appropriate and should be used.

2.6.2.7.5 Limits for Soil Loads and Stress

Recommended limiting values of loads on foundations are the loads that cause stresses at the foundation level or at the level of any weaker underlying strata to equal or exceed safe bearing stresses of the respective soil layers. Allowable or safe bearing pressures may be computed following procedures described in any standard soil mechanics textbook, e.g., Terzaghi & Peck (1967). Recommended limiting values of soil loads on structural members are discussed in Section 2.6.2.7.3.

2.6.2.8 Remedial Action Plan

A remedial action plan should be prepared that lists those parameters related to safety and satisfaction of the 10 CFR Part 61 Subpart C Performance Objectives and those required to verify design assumptions, the respective limiting values or action levels, and appropriate responses to be taken if these values are exceeded. The time required or allowed for necessary responses should also be established and listed. Appropriate responses may include no action, increased monitoring, or completion of remedial actions. These responses should be explicitly identified and justified.

2.6.2.9 Periodic Inspections

Periodic onsite inspections should be made during the construction and operations period, closure period, observation and surveillance period and into the active institutional control period. The periodic inspections should be made by

70

representatives of the licensee and representatives of the licensing authority.

The objectives of such inspections should be to verify design assumptions and satisfactory performance and to determine if any unsafe conditions exist. The initial inspection should be made soon after construction of a unit is complete and before waste placement operations begin. Subsequent inspections should be made at reasonable frequencies to be established based on findings of previous inspections, and evaluation of the instrumentation and monitoring program measurements. All periodic inspections should be fully documented, and a file of such documents should be maintained.

Documentation should include descriptions of the condition of vegetative cover, surface drainage and erosion control features, the waste cover system, disposal units, and auxiliary features. Any changes in conditions since the last inspection should be noted. Any unsafe construction or operating practices should be noted. Documentation should be based on visual inspection and evaluation of instrumentation and monitoring data, as well as QA/QC reports. Recommendations should address actions required to correct any deficiencies observed.

These recommendations should be vigorously enforced to prevent minor deficiencies from worsening. A complete file of periodic inspection reports shall be maintained by the site operator and licensing authority.

2.7 Filter and Drainage Systems

Proper design and construction of the waste cover system should ensure that infiltration is minimized, along with the other requirements stated in Section 2.8. However, it is reasonable to expect that some infiltration of surface water may occur. Therefore, a drainage system should be provided to remove any water that infiltrates through the cover before it reaches the disposed waste packages. In addition, a filter system is required to prevent adjacent fine-grained soil particles in the low-permeability cover from migrating into and clogging the relatively coarse-grained drainage blanket.

Properly designed and constructed filter and drainage systems should be capable of providing long-term satisfactory performance in minimizing the contact of water with waste packages. However, to perform as intended, the filter and drainage system should meet certain fundamental requirements. These fundamental requirements are addressed in this section through recommended general and specific design review criteria. These recommendations address proper selection, gradation, placement, and compaction necessary to achieve design drainage rates and volumes, prevent internal erosion and piping, and allow for collection and removal of liquids.

Important considerations for long-term performance are discussed. Basic components of the filter and drainage system are also discussed, including external and internal components. The components of the system that work to ensure that performance objectives are met are shown in Figure 2.7.1 and include:

a. Free-draining fill around and above waste packages in the tumulus portion of the EMCB, and below, in, and adjacent to the concrete bunkers,

b. Internal drain and collector system, including an external, monitored sump,

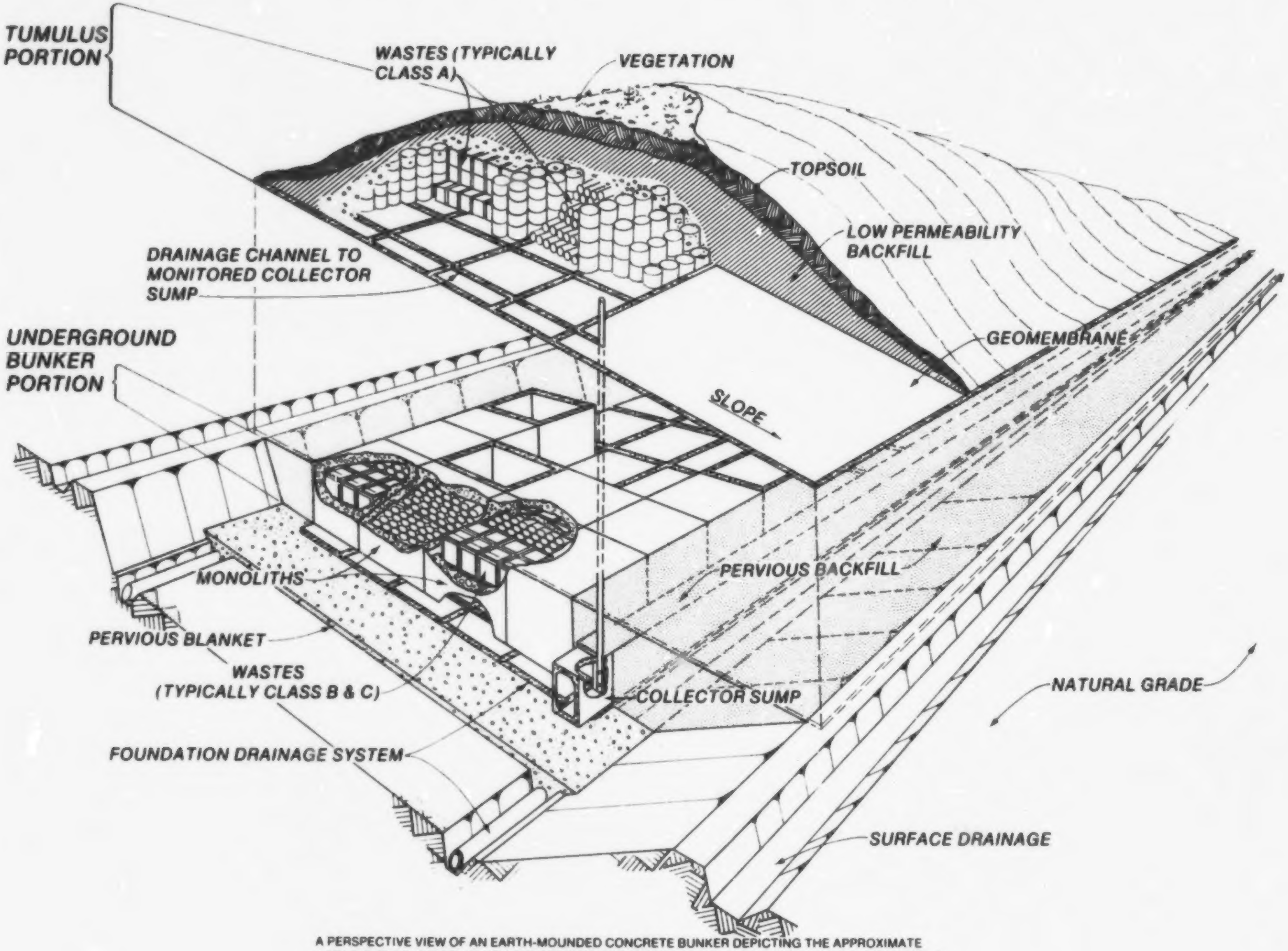
c. Exterior drainage and collector system, including the foundation drainage blanket, drain trench, drain pipe, filter cloth, and a drainage zone.

Monitoring of water levels and flow rates is discussed in Section 2.6.

2.7.1 General Design Criteria for Filter and Drainage Systems

a. Erosion and Piping

Filter and drain systems and materials shall be selected, designed, and constructed to prevent internal erosion and piping of adjacent erodible materials.


TUMULUS PORTION
WASTES (TYPICALLY CLASS A)
VEGETATION
TOPSOIL
LOW PERMEABILITY BACKFILL
DRAINAGE CHANNEL TO MONITORED COLLECTOR SUMP
GEOMEMBRANE
UNDERGROUND BUNKER PORTION
SLOPE
PERVIOUS BACKFILL
MONOLITHS
PERVIOUS BLANKET
WASTES (TYPICALLY CLASS B & C)
COLLECTOR SUMP
NATURAL GRADE
FOUNDATION DRAINAGE SYSTEM
SURFACE DRAINAGE

A PERSPECTIVE VIEW OF AN EARTH-MOUNDED CONCRETE BUNKER DEPICTING THE APPROXIMATE LOCATIONS OF WASTES WHICH ARE SEPARATED ACCORDING TO LEVEL OF ACTIVITY. CLASS B AND C WASTES ARE TYPICALLY PLACED IN CONCRETE MONOLITHS BELOW GROUND. STABILIZED CLASS A WASTES ARE TYPICALLY DISPOSED ABOVE GROUND IN EARTHEN MOUNDS OVER THE CONCRETE MONOLITHS. A DRAINAGE NETWORK IS PROVIDED WITHIN AND AROUND THE STRUCTURE TO PREVENT CONTACT OF WATER WITH THE WASTES AND TO PROVIDE COLLECTION AND MONITORING CAPABILITIES.

Figure 2.7.1. EMCB filter and drainage system

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b. Permeability and Drainage

Filter and drain systems and materials shall be selected, designed, and constructed to promote rapid drainage of any liquid that has infiltrated or otherwise entered the filter and drainage system.

c. Collection, Monitoring, and Removal of Water

Filter and drain systems and materials shall be selected, designed, and constructed to allow collection, monitoring, and removal of liquid that has infiltrated through the cover, or that has condensed or otherwise entered the filter and drain systems.

2.7.2 Specific Design Review Criteria for Filter and Drainage Systems

2.7.2.1 Filters and Drains

2.7.2.1.1 Piping and Internal Erosion

To ensure complete filter protection of erodible materials, i.e. to prevent internal erosion and piping, drainage layers in contact with the soil must not have any continuous openings large enough for the passage of the soil particles. Specifically, the filter should satisfy the following condition:

$$\frac{\text{Max } D_{15} \text{ of filter}}{\text{Min } D_{85} \text{ of soil}} < 4 \text{ to } 5$$

This equation may be stated as:
The 15 percent size (D_{15}) of a filter material must be not more than 4 to 5 times the 85 percent size (D_{85}) of the protected soil. The ratio of D_{15} of the filter to D_{85} of the soil is called the piping ratio. The maximum D_{15} of the band of gradation curves for the filter material is the value to be used in the equation. Similarly, the minimum D_{85} of the protected soil is the value to be used.

Criterion rationale: If a filter layer satisfies this condition in every part, it is virtually impossible for piping to occur, even under extremely large hydraulic gradients (Winterkorn and Fang 1975; Bertram 1940; Cedergren 1967; and U.S. Army Corps of Engineers 1941). Further guidance is provided in Department of the Army Engineer Manual EM 1910-2-1901, Seepage Analysis and Control for Dams (September 1986), Department of the Army Technical Manual TM 5-818-5, "Dewatering and Groundwater Control" (November 1983) and by Cedergren (1967).

74

2.7.2.1.2 Drainage or Permeability

To ensure that all of the liquid reaching the drainage layer can be safely discharged by the drainage layer, even if under small hydraulic gradient and excess head, the drainage layer must be relatively coarse-grained and free-draining. Specifically, the drainage layer should satisfy the following condition:

$$20 > \frac{\text{Min } D_{15} \text{ of filter}}{\text{Max } D_{15} \text{ of soil}} > 4 \text{ to } 5$$

This equation may be stated as:
The minimum 15 percent size (D_{15}) of the filter must be at least 4 to 5 times but less than 20 times the maximum 15 percent size (D_{15}) of the protected soil. This criterion will ensure that filter and drainage layers are several times more permeable than the protected soils, but it does not always ensure adequate hydraulic conductivity of the drain. To ensure adequate hydraulic conductivity of the drainage layer, the following steps should be followed for design:

a. The probable maximum quantities of inflow from the surrounding soil to the drainage layer should be estimated using Darcy's law $q = kiA$, where k is the known value of hydraulic conductivity of the surrounding soil; i is the hydraulic gradient in the direction of flow, and A is the cross-sectional area of the soil normal to the direction of flow.

b. The hydraulic conditions within the drain should be analyzed by rearranging Darcy's Law as:

$$\frac{q}{i} = kA$$

where q is the seepage quantity for which the drain is being designed. This value should be the above-determined probable maximum inflow rate multiplied by a factor between 5 to 10 to provide a reasonable margin of safety. The allowable gradient, i, in the drain should be the maximum gradient considered to be safe or desirable. Realistic values range from 1.0 for vertical drains to 0.01 for horizontal drains. The ratio q/i is the minimum allowable conductivity or transmissibility of the drain.

c. A drain material permeability and blanket thickness should be selected that satisfies the equation above, i.e.

$$q/i = kA$$

where k = effective or average hydraulic conductivity of the drainage material.

A = cross-sectional area of the drain normal to the direction of flow.

Selection should be based on safety considerations and practical and economic considerations of reasonable blanket thickness and permeability of available drainage materials.

If appreciable quantities of water must be drained, graded filters are more efficient and are recommended. Winterkorn and Fang (1975) provide guidance and examples for selection and design of graded and single layer filters and drains.

If actual drain requirements are only approximately known, as is often the case, graded filter or multi-layer drains are highly recommended for assurance of safety and for efficiency.

2.7.2.1.3 Parallel Gradation Curves for Filter and Protected Soil

Grain size gradation curves for the filters and protected soil layers, and for successive filter layers if a graded filter is used, should be approximately parallel. To satisfy this requirement, the following condition should be met:

$$\frac{\text{Max } D_{50} \text{ filter}}{\text{Min } D_{50} \text{ soil}} \leq 25$$

where D_{50} = the 50 percent size of the filter and soil, as indicated.

2.7.2.1.4 Perforated or Slotted Drain Pipe

Perforated or slotted pipe used in filters and drains to facilitate collection of flows should satisfy the following conditions:

D_{85} filter > 1.0 Pipe hole diameter

D_{85} filter > 1.2 Pipe slot width

If these conditions are satisfied, the filter material will not be carried into the pipe. In addition all pipe ends should be plugged or should be connected to solid drain pipe leading to a monitored collector sump. Perforated drain pipe should be fabricated of wire-wrapped stainless steel, slotted Schedule 80 PVC, or other durable materials, such as those discussed in Section 2.6.2.3.1.3 for well screens.

2.7.2.2 Compatibility of Drainage and Filter Materials with the Disposal Environment

2.7.2.2.1 Soil

Drainage and filter materials consisting of free-draining, coarse-grained soils are unlikely to be significantly affected by the disposal environment. In particular, soils composed primarily of quartz particles are very stable and highly resistant to both chemical and physical weathering. The silica tetrahedra that form quartz are arranged in a firmly braced 3-D network. All bonds are primary valence bonds. The mineral has no easy cleavage, is very hard, and is nearly insoluble in all common acids.

Feldspar, another common mineral constituent found in sands has a structure similar to quartz with one major exception, i.e. some of the silicon atoms in the tetrahedra have been replaced with aluminum atoms. This substitution (Al^{+3} for Si^{+4}) leaves the crystal with an unbalanced charge. The charge is normally balanced by taking in cations such as K^{+}, Na^{+}, and Ca^{+2}, resulting in orthoclase, albite, and anorthite, respectively. This resulting space lattice structure causes distortion of the crystal and cleavage. Therefore, feldspar is less resistant than quartz to chemical and physical weathering processes, but is a relatively stable mineral.

Less stable minerals found in soils include the sheet silicates, e.g. mica, clay minerals, e.g. kaolinite; and carbonate minerals, e.g., calcite. However, most coarse-grained soils are composed primarily of quartz and feldspar minerals and are therefore quite resistant to physical and chemical weathering. Therefore, such soils should make excellent choices for drainage and filter materials. Otherwise acceptable soils should be tested for substances that may degrade drain pipe performance as discussed in the following section.

2.7.2.2.2 Drain Pipes

While the soil grains that are likely to be used for filter and drainage materials are not likely to be adversely affected by the disposal environment, the perforated and solid pipe and the pores in the soil mass near the pipes that permit drainage are likely to be clogged with time. There are no known unique or unusual characteristics of the LLW that cause this degradation. However, constituents in the soil and water found in the general environment in which drains must operate frequently do result in corrosion and encrustation. Iron-reducing bacteria are the most common bacteria that cause plugging of soil pores and drain pipes. Iron-reducing bacteria produce accumulations of slimy material of gel-like consistency, and oxidize and precipitate dissolved iron and manganese (Driscoll 1986). These substances can completely clog pipes.

Calcium carbonate and magnesium carbonate, common causes of "hardness" in drinking water supplies, are frequently deposited in the pipes and nearby soil mass. The concentrations of Ca^{+2} and Mg^{+2} ions dissolved in the water exceed saturated soluble levels as flow velocities increase toward the drain pipe. This condition and the higher levels of carbon dioxide and oxygen normally found in the pipes are conducive to the formation of calcium carbonate and magnesium carbonate. These chemical compounds can be deposited on the pipe walls and can completely encrust and clog pipes.

There are no known methods or materials that can be used to completely prevent drain degradation. However, certain measures have been shown to be effective in reducing the severity of the clogging and encrustation of pipes and soil pores and in rehabilitating such drains. These measures are summarized below. Additional guidance is provided by Driscoll (1986).

a. Measures to Reduce Problems:

1. Filter and drainage soil materials should be tested prior to acceptance to ensure that they do not contain iron, chlorides, sulfates, or other chemical compounds that would cause corrosion or encrustation of drainage pipes.

2. Pipes should be thoroughly steam-cleaned and protected and stored in a clean location prior to installation.

3. Care should be taken to avoid bacteriological contamination of drain pipes during handling and installation.

4. Pipe materials that are resistant to corrosion and encrustation should be used, such as stainless steel, thermoplastic (e.g. PVC), or fiberglass. Thermoplastic and fiberglass are more resistant to corrosion than stainless steel, but just as susceptible to encrustation. These materials are also more resistant than metal to damage from rehabilitation measures that use strong chemicals. However, stainless steel is more resistant to damage from rehabilitation measures that involve vigorous physical abrasion and scraping, i.e. jetting and surging, and inhibitors can be added to the chemicals used to minimize any damage.

b. Measures for Rehabilitating Clogged Drains

The methods available for cleaning clogged drains (and wells) involve the use of either physical abrasion and scouring, injection of chemicals, or a combination of these methods. Commonly used methods are listed below:

1. Steam cleaning
2. Wire brushing
3. Jetting
4. Surging
5. Air lifting
6. Injecting chlorine
7. Injecting acids.

Driscoll (1986) discusses the use of these measures. A detailed discussion of measures for rehabilitating drains and wells is beyond the scope of this report. Research being performed by personnel of the Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station may provide solutions for reducing the severity of degradation of drains and better methods for rehabilitating them.

2.7.2.3 Standards and Test Methods for Drainage Pipe

Available ASTM Standards for drainage pipe are cited below by pipe material type. Applicability of specific standards should be addressed based on specific site conditions and intended use.

Concrete Pipe

C 14	Specification for Concrete Sewer, Storm Drain; and Culvert Pipe
C 76	Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
C 118	Specification for Concrete Pipe for Irrigation or Drainage
C 412	Specification for Concrete Drain Tile
C 497	Method of Testing Concrete Pipe, Sections or Tile

Asbestos-Cement Pipe

C 500	Method of Testing Asbestos-Cement Pipe

Plastic Pipe

D 1598	Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
D 1599	Test Method for Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings
D 1694	Specification for Threads for Reinforced Thermosetting Resin Pipe
D 2105	Test Method for Longitudinal Tensile Properties of Reinforced Thermosetting Plastic Pipe and Tube
D 2122	Method for Determining Dimension of Thermoplastic Pipe and Fittings
D 2290	Test Method for Apparent Tensile Strength of Ring or Tubular Plastics and Reinforced Plastics by Split Disk Method

D 2310	Classification for Machine-Made Reinforced Thermosetting Resin Pipe
D 2321	Recommended Practice for Underground Installation of Flexible Thermoplastic Sewer Pipe
D 2412	Test Method for External Loading Properties of Plastic Pipe by Parallel-Plate Loading
D 2444	Test Method for Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tap (Falling Weight)
D 2749	Symbols for Dimensions of Plastic Pipe Fittings
D 2855	Recommended Practice for Making Solvent-Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings
D 2925	Test Method for Beam Deflection of Reinforced Thermosetting Plastic Pipe Under Full Bore Flow
D 2996	Specification for Filament-Wound Reinforced Thermosetting Resin Pipe
D 2997	Specification for Centrifugally Cast Reinforced Thermosetting Resin Pipe
D 3262	Specification for Reinforced Plastic Mortar Sewer Pipe
D 3311	Specification for Drain, Waste, and Vent (DWV) Plastic Fittings Patterns
D 3567	Method for Determining Dimensions of Reinforced Thermosetting Resin Pipe (1TRP) and Fittings
D 3681	Test Method for Chemical Resistance of Reinforced Thermosetting Resin Pipe in a Deflected Condition
D 3754	Specification for Reinforced Plastic Mortar Sewer and Industrial Pressure Pipe
D 3839	Practice for Underground Installation of Flexible Reinforced Thermosetting Resin Pipe and Reinforced Plastic Mortar Pipe
D 3840	Specification for Reinforced Plastic Mortar Pipe Fittings for Non-Pressure Applications
D 4024	Specification for Reinforced Thermosetting Resin (RTR) Funges
D 4160	Specification for Reinforced Thermosetting Resin Pipe (RTRP) Fittings for Nonpressure Applications

D 4184 Specification for Reinforced Thermosetting Resin (RTRP) Sewer Pipe

2.7.2.4 Interior Drainage and Collector System

2.7.2.4.1 Specific Criteria for Features of Interior Drainage and Collector System

The following paragraphs summarize and discuss criteria for features of the interior drainage and collector system and Figure 2.7.2 shows the components.

The EMCB interior drainage and collector system should be designed and constructed to promote rapid drainage and minimize the ponding of water on the bunker or tumulus floor and subsequent contact with waste packages.

2.7.2.4.2 Free-draining Fill Around Waste Packages

Filling of voids between waste packages is required by 10 CFR Part 61, paragraph 61.52(a)(5) for the purpose of reducing future subsidence. Free-draining backfill should be placed in the voids between waste packages and EMCB interior surfaces to enhance waste isolation capabilities and stability of the disposal unit and site. Fill should be selected that is compatible with the disposal vault environment and that avoids adverse impacts on waste packages and the EMCB disposal units.

Appendix A of SRP 4.3, NUREG 1200, and Tucker (1983) provide guidance on selection and placement of fill around waste packages. This guidance was developed for trench-type near-surface disposal but is equally applicable to EMCB disposal of LLW.

The structural roof of the bunker should be designed to be stable without support from the fill placed in the interior of the vault. However, filling of voids between waste packages and filling up to the roof should be done to provide an additional conservative measure to disposal site stability.

Compaction of fill between waste packages is not recommended because there is no practical way to perform this activity and because of concern for increased exposure of workers to radiological hazards.

2.7.2.4.3 Floors

Bunker floors should be reinforced concrete, finished with a uniform gentle slope toward the interior collector along one side of the bunker. Super flat floor specifications are not required, but depressions and high areas should be minimized to the extent possible for normal construction practices.

2.7.2.4.4 Interior Collector

The bunker interior collector should be a depressed channel that extends the full length of the bunker along one or both sides. The collector channel should be formed with a gentle slope toward the drain exit prior to placement of the concrete floor. The drain openings for the collectors should be fitted with a protective grate to facilitate operations and reduce the risk of operational accidents. Figures 2.7.2a and b illustrate one concept for the interior drain and collector components.

2.7.2.4.5 Acceptance Tests

The bunker floor, collector, and drain should be tested prior to placement of any waste to ensure that the system functions properly. High areas and depressions in the slab should be corrected or repaired.

2.7.2.4.6 Drain Opening

The drain exit opening and pipe should be properly sized and sufficiently large to convey all collected water to the exterior drain sump in a reasonably short time. The joint between the drain pipes and exterior opening must be carefully sealed with a durable sealant to minimize the possibility of leakage at these points.

2.7.2.4.7 Solid Drain Pipe

Solid drain pipe should be designed and selected that is adequate for anticipated loads and flow rates. Pipe should be selected that is durable and resistant to bacteriological clogging, encrustation, and capable of withstanding rehabilitation measures, as discussed in Section 2.7.2.2.2.

Solid drain pipe should be sloped from the exit drain in the EMCB to the monitored collector sump. The pipe should enter the sump near the top. A solid drain pipe should exit the sump near the top and slope toward the discharge at a gentle slope sufficient to ensure gravity flow.

2.7.2.4.8 Monitored Collector Sump

The collector sump is considered part of the interior system, although it is located on the exterior of the bunker. The collector sump should be fabricated of durable materials and designed for all appropriate structural loads. Collector sump materials may include reinforced concrete, fiberglass, or other materials that can be shown to be durable in the environment that they are placed. Collector sump materials must not have an adverse impact or masking effect on monitoring.

Openings in the collector sump for the inlet and outlet drains and a monitoring well should be formed at the time of manufacture of the sump and should be designed to allow a good seal to be formed between the openings and pipes. Figure 2.7.2 shows a section view of a collector sump that should be capable of satisfying these requirements.

2.7.2.5 Exterior Filter and Drainage Systems

The exterior filter and drainage system should surround the EMCB and divert any water that has infiltrated through the cover away from the wastes to the foundation drain. The system should be designed to prevent internal erosion and piping of the overlying cover and adjacent soils. Water that enters the drain should be monitored to determine inflow quantities and should be sampled and tested for radiological contamination and hazardous constituents prior to discharge. The elements of the exterior filter and drainage system include the drain, the drainage blanket constructed on the excavation floor on which the bunker floor is cast, and the drainage blanket surrounding the bunker sides and roof. These components are shown in Figure 2.7.3. and Figure 1.1, and are discussed separately in the following paragraphs. Applicable standards and tests methods for pipe are given in Section 2.7.2.3. Selection of soil and pipe materials for the exterior drain system should be based on considerations discussed in Sections 2.7.2.1 and 2.7.2.2.

2.7.2.5.1 Drain

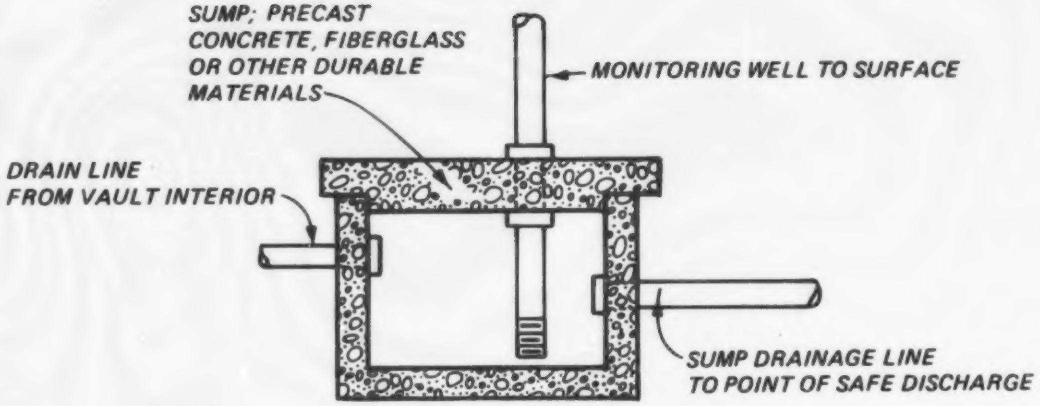
The drain should satisfy all the general design criteria of Section 2.7.1 and the specific design review criteria of Section 2.7.2. Drain components are discussed in Sections 2.7.2.5.1.1 through 2.7.2.5.1.6.

2.7.2.5.1.1 Trench

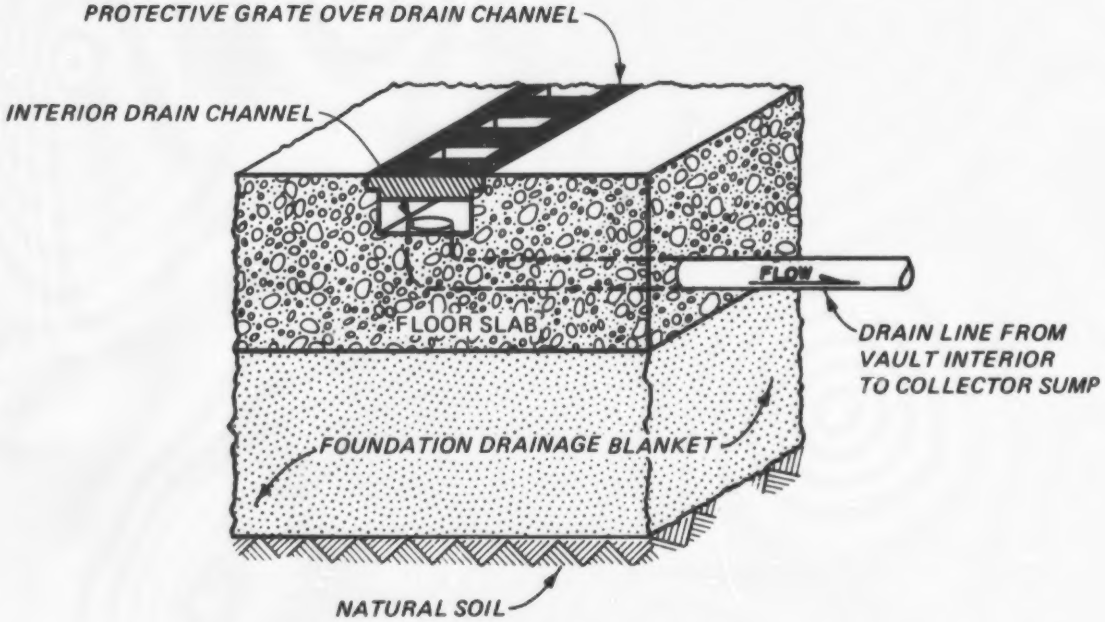
The drain trench should be excavated along the full length of the bunker on the low side of the sloped excavation bottom. The trench should be sized to handle design flows, with a sufficient margin of safety. All loose material should be removed from the trench and any sharp projections should be removed and undulating surfaces smoothed to provide a uniformly sloped, smooth bedding surface for the drain pipe.

2.7.2.5.1.2 Filter Cloth

Filter cloth capable of providing flow capacity adequate to prevent significant hydrostatic pressures from developing in the soil that is being drained and preventing soil particles from migrating into the trench and plugging the drain should be installed in the trench. Section 2.3.3.5.3 discusses geotextiles including appropriate filter cloth standards. The filter cloth should extend across the bottom, up the sides of the trench, and should lap over the top of the trench. Alternatively, the pipe may be wrapped before backfilling the trench.


SUMP; PRECAST
CONCRETE, FIBERGLASS
OR OTHER DURABLE
MATERIALS
MONITORING WELL TO SURFACE
DRAIN LINE
FROM VAULT INTERIOR
SUMP DRAINAGE LINE
TO POINT OF SAFE DISCHARGE

(a) Section view of collector sump for interior drain system


PROTECTIVE GRATE OVER DRAIN CHANNEL
INTERIOR DRAIN CHANNEL
FLOW
FLOOR SLAB
DRAIN LINE FROM
VAULT INTERIOR
TO COLLECTOR SUMP
FOUNDATION DRAINAGE BLANKET
NATURAL SOIL

(b) Section view detail of interior collector system

Figure 2.7.2. Interior collector and drain system

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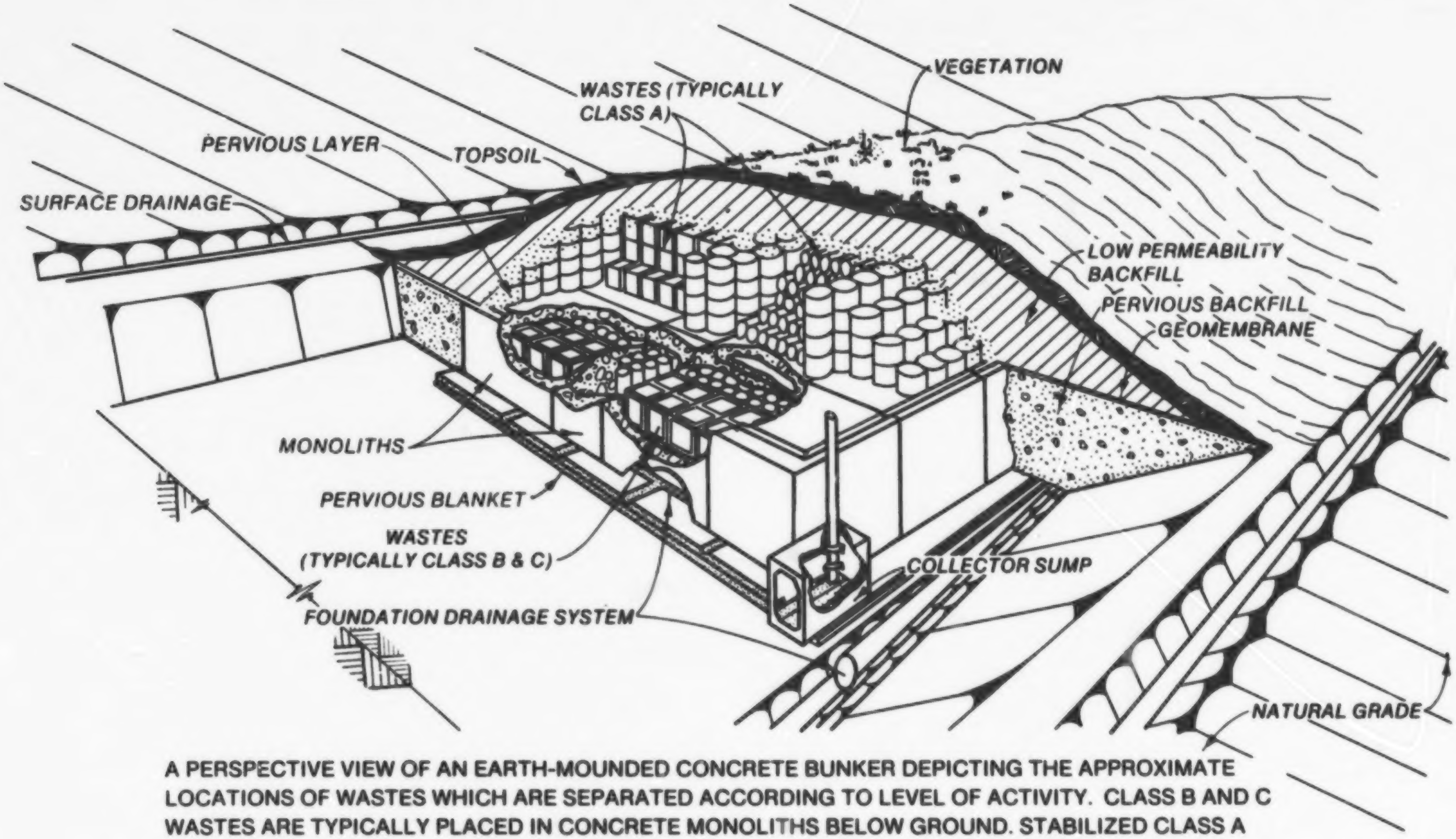
84


VEGETATION
WASTES (TYPICALLY CLASS A)
PERVIOUS LAYER
TOPSOIL
SURFACE DRAINAGE
LOW PERMEABILITY BACKFILL
PERVIOUS BACKFILL
GEOMEMBRANE
MONOLITHS
PERVIOUS BLANKET
WASTES (TYPICALLY CLASS B & C)
COLLECTOR SUMP
FOUNDATION DRAINAGE SYSTEM
NATURAL GRADE

A PERSPECTIVE VIEW OF AN EARTH-MOUNDED CONCRETE BUNKER DEPICTING THE APPROXIMATE LOCATIONS OF WASTES WHICH ARE SEPARATED ACCORDING TO LEVEL OF ACTIVITY. CLASS B AND C WASTES ARE TYPICALLY PLACED IN CONCRETE MONOLITHS BELOW GROUND. STABILIZED CLASS A WASTES ARE TYPICALLY DISPOSED ABOVE GROUND IN EARTHEN MOUNDS OVER THE CONCRETE MONOLITHS. A DRAINAGE NETWORK IS PROVIDED WITHIN AND AROUND THE STRUCTURE TO PREVENT CONTACT OF WATER WITH THE WASTES AND TO PROVIDE COLLECTION AND MONITORING CAPABILITIES.

2.7.3 Exterior filter, drain, and collector details

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2.7.2.5.1.3 Perforated Drain Pipe

Perforated drain pipe should be selected in accordance with guidance and specific criteria given in Sections 2.7.2.1 and 2.7.2.2 and should meet appropriate ASTM specifications cited in Section 2.7.2.3, including specifications for joints. Plastic perforated pipe is covered by the same ASTM specifications listed for solid plastic drain pipe.

2.7.2.5.1.4 Free-Draining Soil Fill

Free-draining soil fill meeting the specific design review criteria of 2.7.2.1 through 2.7.2.3 should be placed and compacted beneath, around, and above the pipe. Placement and compaction should be performed in accordance with guidance provided in Section 2.7.2.6.

2.7.2.5.1.5 Foundation Drainage Blanket

Thickness, grain size, mineral composition, and gradation of the foundation drainage blanket should be selected in accordance with recommendations of 2.7.2.1 through 2.7.2.3 to ensure rapid drainage. As discussed in 2.7.2.1, the drainage blanket must satisfy two distinct requirements; i.e. it must promote rapid drainage and it must prevent erosion and internal piping of adjacent fine-grained materials. Suitable filter fabrics may also be used to complement the soil's ability to satisfy the filter criterion. Use of filter fabrics alone to satisfy filter and drain criteria is not recommended because of questions concerning long term performance and durability. The foundation drainage blanket should be compacted in accordance with Section 2.7.2.6.

2.7.2.5.1.6 Drainage Zone Within the EMCB

The drainage zone placed within the EMCB should satisfy the same criteria recommended in 2.7.2.1 through 2.7.2.3. Placement and compaction criteria are recommended in Section 2.7.2.6.

2.7.2.5.2 Trench Monitoring Wells

Provisions may be made for monitoring the exterior trench drainage. Design is similar to that for wells monitoring interior drainage except that the screened section bottoms are in sand within the trench drain rather than in an open prefabricated sump such as used for the bunker. The difference will require special attention to sealing the interface between riser pipe and drain.

Other details of monitoring wells are found in Section 2.6.2.3.

2.7.2.6 Placement and Compaction of Free-Draining Fill

The foundation drainage layer and the drainage materials placed in the drain and drainage zone should be placed and compacted

86

according to guidance provided in Department of the Army Technical Manual TM 5-818-4. Additional specific recommendations are given below.

2.7.2.6.1 Unrestricted Areas

In unrestricted areas, where normal high volume compaction equipment can operate, the drainage layer materials should be placed in lifts of not more than 10 in. loose thickness. Each lift should be compacted using equipment and methods that have been shown to produce satisfactory results, such as vibratory steel-wheel or rubber tire rollers. The fill should be placed air-dry or at 90 to 100 percent of saturation moisture content. If field tests establish that the required density can be achieved within the specified compactive effort without strict adherence to the moisture content specification, then the moisture content specification may be relaxed.

2.7.2.6.2 Restricted Areas

In restricted areas, such as immediately adjacent to bunker foundations and walls, drainage fill should be placed in not more than 6-in. loose-lift thicknesses and compacted using equipment and methods that have been shown to produce satisfactory results, such as a vibratory compactor. The compactor should have a minimum weight of 100 lbs. The fill should be placed air-dry or at 90 to 100 percent of saturation moisture content.

2.7.2.6.3 Fill Acceptance Criteria

Fill acceptance of the drainage materials should be based on the achievement of specified relative density for each lift of granular fill placed, according to the following acceptance criteria:

a. Relative density determined by any single field test must be at least 75 percent.

b. Cumulative relative density as measured by all tests must be at least 80 percent.

Relative density is defined by the equation

$$D_R\% = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

where:

D_r = relative density expressed as a percent
e_{max} = void ratio of soil in its loosest state
e_{min} = void ratio of soil in its densest state
e = void ratio of soil in its compacted state

Relative density may also be expressed in terms of dry unit weights, using the equation below:

$$D_R\% = \frac{\gamma_d - \gamma_{d_{min}}}{\gamma_{d_{max}} - \gamma_{d_{min}}} \times \frac{\gamma_{d_{max}}}{\gamma_d} \times 100$$

where:

γ_d = dry unit weight of in place soil

$\gamma_{d_{min}}$ = dry unit weight of soil in the loosest state which can be attained in the laboratory minimum density test

$\gamma_{d_{max}}$ = dry unit weight of soil in the densest state which can be attained in the laboratory maximum density test

2.7.2.6.4 Field Acceptance Test Methods and Frequencies

a. Field Density. The sand cone density test ASTM D 1556 or other suitable standardized accurate tests should be used to determine field densities. Selection of sand cone size should be based on gradation and maximum particle size of the drainage materials to provide reasonable and acceptable test results. At least one (1) field density test per 2,000 ft^2 of each lift should be performed in unrestricted areas. At least one (1) test should be performed per 100 yd^3 of fill placed in restricted areas. All field density tests will be performed within a depth interval of 6 to 14 in. below the surface of the uppermost compacted lift.

b. Maximum and minimum dry density. Maximum and minimum dry density determinations shall be in accordance with ASTM D 4253 and D 4254, respectively. At the start of fill placement, at least 5 maximum density tests should be performed. At least one (1) additional maximum density test should be performed per 200 yd^3 of fill placed in restricted or unrestricted areas or when material type changes. For similar materials, the value of maximum density used for construction quality control acceptance should be the combined average of all tests. The average should be recomputed after each five (5) additional tests.

Preliminary maximum dry density tests should be performed at moisture contents between 90 percent and 100 percent saturation and using rheostat settings between 50 and 100 on the vibrating table. The moisture content and rheostat setting that produces the maximum dry density should then be used for all subsequent tests.

Preliminary minimum dry density tests should be performed using both the flat scoop and graduate cylinder methods, to determine which method gives the minimum dry density and most reproducible results. The method giving the lowest dry density should then be adopted for all subsequent minimum dry density determinations. At least five (5) tests should initially be made and the results averaged to determine minimum dry density. At least one (1) additional minimum dry density test should be made per 200 yd^3 of fill placed in restricted or unrestricted areas or when materials type changes. The minimum dry density should be recomputed after each five (5) minimum dry density tests.

2.7.2.6.5 Certification of Compliance

The license applicant should verify that these criteria and specifications on placement and compaction have been met and should document all instances of noncompliance and action taken.

2.8 Waste Cover Systems

Figure 2.8.1 shows the major components of the waste cover system in the tumulus portion of the EMCB including: (1) the vault roof, (2) low-permeability membranes, (3) backfill around waste packages, (4) filter and drainage layer materials, (5) low-permeability soil layers, (6) topsoil and vegetation, and possibly rock protection of final surfaces. Guidance and criteria for backfill around waste packages and for filter and drainage materials are provided in Section 2.7. Guidance on the design of rock protection is provided in SRP 5.1.1 of NUREG-1200. Other sections of NUREG-1200 provide guidance on design and construction of the waste cover system, but it is intended that this section expand on existing guidance and more directly address special considerations related to the EMCB. Technical quidance prepared for EPA (Lutton 1987) on similar engineered covers over hazardous waste may also be useful.

2.8.1 General Design Criteria for Waste Cover Systems

Waste cover systems should be designed and constructed of suitable materials using methods that provide reasonable assurance that the completed cover system satisfies the Performance Objectives of 10 CFR Part 61 Subpart C. Performance of the cover system should be judged on its capability for:

a. Directing surface runoff away from the disposal unit and wastes.

b. Minimizing infiltration of runoff through the cover and toward the disposed wastes.

c. Minimizing the contact of water with waste packages during disposal and the contact of percolating or standing water with waste packages after disposal.

d. Minimizing surface erosion, differential settlement, ponding, piping, sloughing, and slumping.

e. Protecting inadvertent intruders, for 500 years, from Class C wastes.

f. Limiting the dose rate at the surface of the cover to acceptable levels.

g. Providing long-term stability without the need for active maintenance.

2.8.2 Specific Design Review Criteria for Waste Cover Systems

2.8.2.1 Vault Roofs

Considerations related to structural loading, design, material quality, construction operations, and performance for the vault

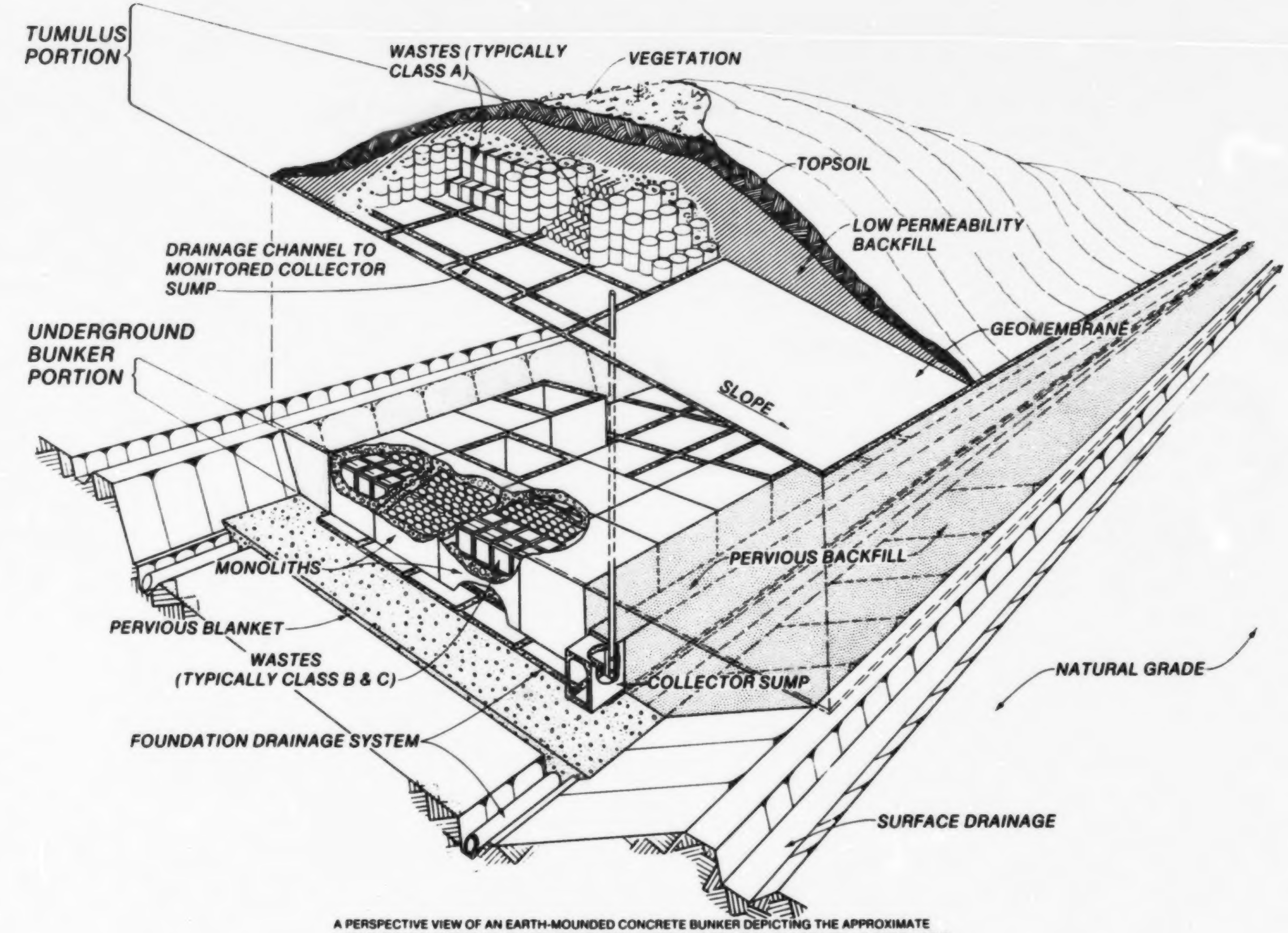
TUMULUS PORTION
WASTES (TYPICALLY CLASS A)
VEGETATION
TOPSOIL
LOW PERMEABILITY BACKFILL
DRAINAGE CHANNEL TO MONITORED COLLECTOR SUMP
GEOMEMBRANE
UNDERGROUND BUNKER PORTION
SLOPE
PERVIOUS BACKFILL
MONOLITHS
PERVIOUS BLANKET
WASTES (TYPICALLY CLASS B & C)
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Figure 2.8.1. Major components of EMCB waste cover system

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roof are covered in the preceding sections. In general, concrete that is strong and dense will also have low permeability, i.e. the design and construction considerations necessary to achieve these goals are the same and include low water to cement ratios, good vibration, adequate curing, and careful attention to sealing of joints and control of cracks. In addition, the roof should be sloped to promote drainage toward the sides of the bunker. The license applicant should provide plans and a discussion of features designed to achieve low permeability and watertightness of the vault roof along with a description of the features required to permit filling of void space between the roof and the disposed waste. If the vault roof is designed to be a barrier to inadvertent intrusion, it must be shown to provide intruder protection for Class C wastes for 500 years.

2.8.2.2 Low-Permeability Cover Materials

Low-permeability cover materials should be designed and constructed to minimize ponding and infiltration of water. Refer to SRP 6.2 of NUREG-1200 for guidance on protection of inadvertent intruders. Cover materials should be designed and constructed to limit the dose rate at the surface to acceptable levels, to minimize the potential for slumping, sloughing, or sliding, and to minimize the adverse effects of burrowing animals. Cover materials should be compatible with and complement the performance of drainage and filter materials and surface drainage and erosion protection features of the disposal site. Low-permeability cover materials include the earth or man-made materials placed above the structural roof of the disposal unit.

2.8.2.2.1 Low-Permeability Membranes

Low-permeability membranes and panels, if proposed by the license applicant, should be designed and constructed to complement the bunker's roof and the low-permeability earth cover capabilities for minimizing infiltration of water and possible contact with waste packages. Section 2.3.3.5.2 summarizes the main characteristics and qualities of geomembranes and accepted methods of construction. Another low-permeability material that may be successfully used is corrugated panels with bentonite sandwiched between the corrugations. Characteristics of bentonite panels were summarized in Section 2.3. Such panels have been successful in sealing tunnels driven beneath water bodies.

Use of geomembranes, bentonite panels, or other low-permeability manufactured materials should be considered if the locally available low-permeability soils have only marginally acceptable performance characteristics or as an added measure of conservatism. These materials should not be considered substitutions for acceptable earth covers. Use of low-permeability membranes as a barrier placed over the vault roof and walls is illustrated in Figure 2.8.1.

2.8.2.2.2 Low-Permeability Earth Cover

Construction of low-permeability earth covers are briefly discussed in Section 2.4. To achieve its intended design function, low-permeability earth covers that normally would consist of clay materials should be carefully selected, placed, and compacted. Guidance on selection, placement, and compaction is given in the following paragraphs. However, substitutions may be necessary or beneficial and this guidance should not be absolute. For example, some fine-grained soils are difficult to compact properly and may require processing prior to placement and the construction of test fills to develop satisfactory methods for placement and compaction. Further, soils with a high percentage of fines tend to be more susceptible to frost heave, which should be a consideration in seasonal frost areas. Thick clay covers offer the advantage of increasing the travel time for infiltrating water and reducing problems with desiccation cracks, but difficulty in properly compacting thick clay covers may increase settlements. Organic silts, organic clays, and peats should be avoided because of their unstable composition, difficult placement and compaction characteristics and high compressibility.

The in-place coefficient of permeability of the compacted clay material in any direction should be less than or equal to 1×10^{-7} cm/sec as measured by tests on undisturbed samples of the cover layer according to the Corps of Engineers EM 1110-2-1906, "Laboratory Soils Testing", Appendix VII, Chapter 7, "Permeability Tests with Back Pressure" (November 1970). The thickness of the clay layer in the cover system should be at least 2 ft. To minimize potential settlement problems due to improper compaction, maximum thickness of the clay cover should be 6 ft. The upper surface of the clay layer should be crowned, i.e. it should slope toward the sides. The low-permeability clay layer should be placed and compacted according to Department of the Army Technical Manual TM-5-818-4 "Backfill for Subsurface Structures," Appendix B, "Fundamentals of Compaction, Field Compaction Test Methods, and Field Moisture-Density Test Methods." Additional guidance is offered in the following paragraphs.

2.8.2.2.2.1 Placement and Compaction

2.8.2.2.2.1.1 Unrestricted Areas

In unrestricted areas where normal, high-volume compaction equipment can be used, the low-permeability clay cover should be placed in not more than 10-in. loose-lift thicknesses and should be compacted to 95 percent of the maximum dry density as determined by the Modified Proctor Method, ASTM D 1557. The placement moisture content should be within -1 to +2 percent of the optimum moisture content.

93

2.8.2.2.2.1.2 Restricted Areas

In restricted areas, the low-permeability clay soil should be placed in not more than 4-in. loose-lift thicknesses and compacted to 95 percent of the maximum dry density as determined by the Modified Proctor Method, ASTM D 1557. The placement moisture content should be within -1 to +2 percent of optimum moisture content.

2.8.2.2.2.2 Fill Acceptance Criteria

Acceptance of compaction of the low-permeability earth cover should be based on achievement of a specified minimum dry density and achievement of a specified placement moisture content for each lift placed. A compacted lift should be judged acceptable if:

1. The in-place dry density determined by any single test is at least 93 percent of the maximum dry density as determined by the Modified Proctor Method, ASTM D 1557, and the in-place moisture content is within -1 to +2 percent of optimum moisture content.

2. The cumulative average dry density as measured by all tests within one lift is at least 95 percent of the maximum dry density as determined by ASTM D 1557 and the average in-place moisture content is within -1 to +2 percent of optimum moisture content.

2.8.2.2.2.3 Fill Acceptance Test Methods and Frequencies

1. Field tests to judge acceptance of the low-permeability earth cover fill should be performed according to ASTM D 1556, the sand cone density method. At least one test should be performed per 2,000 ft^2 in unrestricted areas. At least one test should be performed per 100 yd^3 of fill placed in restricted areas. At least one test should be performed whenever it is suspected that fill material characteristics have changed.

2. Maximum Density. Maximum dry density should be determined in accordance with ASTM D 1557. Initially, one five-point ASTM D 1557 test should be run to determine maximum dry density. At least one additional test should be run for each 200 yd^3 of fill placed in restricted or unrestricted areas or when material type changes. The dry density value used as 100 percent maximum dry density will be the average of all maximum test values for a specific soil material type. The optimum water content should be the average corresponding to the maximum dry density.

94

2.8.2.2.2.4 Certification of Compliance

The license applicant should verify that these criteria and specifications have been met and should document all instances of noncompliance and actions taken.

2.8.2.3 Topsoil and Vegetation

Topsoil and vegetation should be selected and placed that complement the ability of the disposal site to meet the Performance Objectives of Subpart C and pertinent Technical Requirements of Subpart D of 10 CFR Part 61. Specifically, topsoil and vegetative cover materials should be capable of resisting erosion, promoting runoff, and minimizing ponding and infiltration. In addition, in seasonal frost areas, topsoil should be selected that is resistant to frost heave. Department of the Army Engineer Manual EM-1110-3-136 (April 1984) provides guidance on prevention of frost damage and maximum depth of frost penetration in the U.S. Soil types that are susceptible to frost heave and those that are "frost free" are discussed in Terzaghi and Peck (1967) and Peck, Hanson, and Thornburn (1973), including conditions that can result in formation of ice lenses and means for preventing frost damage. Table 2.8-2 lists susceptibility of soil types to freeze action. The tendency for ice lenses to develop and grow increases rapidly with decreasing grain size and percentage of grains smaller than 0.02 mm. However, the rate at which available water can flow toward the zone of freezing decreases with decreasing grain size. Therefore, the worst soils for frost heave damage susceptibility tend to be the intermediate grain size soils, such as fine silts and sand-silt mixtures. For a soil with given grain-size characteristics, the intensity of ice lens growth increases with increasing compressibility. Vegetation should be selected such that root systems do not significantly penetrate the low-permeability earth cover. Department of the Army Technical Manual TM 5-830-2, "Establishment of Herbaceous Ground Cover" (September 1983), and Tucker (1983) provide guidance on selection of plants. Table 2.8-1 is provided to give typical values for rooting depths. The actual selection of species should address the conditions associated with the specific region of the country and habitat. Topsoil should be selected that promotes establishment and nourishment of the selected vegetative cover. On-site soils and native vegetation may be used if these soils and vegetation are capable of fulfilling the intended function regarding long-term stability.

Topsoil should be compacted to minimize erosion. Compaction efforts should be less than for the low-permeability earth cover materials to encourage vegetation growth. The topsoil should be compacted to 90 percent of the maximum dry density as determined by the Modified Proctor Method, ASTM D 1557. Placement moisture content should be within -2 to +3 percent of the

95

optimum moisture content. Roots and other debris should be removed from topsoil before placement.

Soil types classified according to the Unified Soils Classification System (USCS) (Sowers 1979), are ranked in Table 2.8-2 according to their performance of certain cover functions (1 = best, 13 = worst). Selection of satisfactory soil for the topsoil layer should be based on resistance to water and wind erosion, resistance to infiltration, resistance to burrowing animals, and freeze resistance. Substitutions may be required to balance these somewhat contradictory requirements, according to the rankings in Table 2.8-2 and should include consideration of available materials. For example, it may be desirable that only soils with a ranking less than 5 for impeding water percolation be used in topsoil layers. However, other considerations may, under specific conditions, indicate a need to deviate from this requirement, e.g., to achieve adequate resistance to erosion.

Two useful formulas in these areas are the United States Department of Agriculture (USDA) universal soil loss equation (USLE) and the wind erosion equation (WEE). The USLE is stated as:

$$A = RKLSCP$$

where

A = average soil loss (tons/acre)
R = rainfall and runoff erosivity index
K = soil erodibility factor
L = slope - length factor
S = slope - steepness factor
C = cover/management factor
P = practice factor

The WEE is written as:

$$A' = f(K', C', L', T', V')$$

where

K' = a soil erodibility factor
T' = a soil ridge roughness factor
C' = a climatic factor
L' = the field length along the prevailing wind erosion direction
V' = an equivalent quantity of vegetative cover

An in-depth review of the use of the formulas as well as the factors that make them up is provided by Tucker (1983).

Table 2.8-1

Typical Rooting Depth of Various Plants*

(Source: T. E. Hakonson and E. S. Gladney, 1981)

Species	Root Depth Feet	Root Depth Meters
Blue Grama	3	1
Cheatgrass	3	1
Russian Thistle	8	6
Sweet Clover	15-30	5-10
Rabbit Brush	15	5
Sage Brush	15	5
Ponderosa Pine	9-12	3-4

---

* Table 2.8.1 is provided to give typical values for rooting depths. The actual selection of species should address the conditions associated with the specific region of the country and habitat.

Table 2.8-2

Ranking of USCS* Soil Types

(Source: EPA-60012-79-165 "Design and Construction of Covers for Solid Waste Landfills")

USCS Symbol	Erosion Control Water	Erosion Control Wind	Impede Water Percolation	Assist Water Percolation	Discourage Burrowing	Gas Migration Impede	Gas Migration Assist	Support Vegetation	Crack Resistance	Reduce Freeze Action Fast Freeze**	Reduce Freeze Action Saturation
GW	1	1	10	3	1	10	1	10	1	10	1
GP	1	1	12	1	1	9	2	10	1	9	1
GM	4	3	7	6	3	7	4	6	3	7	4
GC	3	5	5	8	5	4	7	5	5	4	7
SW	2	2	9	4	2	8	3	9	1	8	2
SP	2	2	11	2	2	7	4	9	1	7	2
SM	6	4	8	5	4	6	5	2	2	6	5
SC	7	6	6	7	6	5	6	1	4	5	6
ML	13	7	4	9	7	3	8	3	6	3	10
CL	12	8	2	11	8	2	9	7	8	2	8
OL	11	7	—	—	7	—	—	4	7	—	8
MH	10	9	3	10	9	—	—	4	9	—	9
CH	9	10	1	12	10	1	10	8	10	1	3
OH	8	—	—	—	—	—	—	8	9	—	—
Pt	5	—	—	—	—	—	—	3	—	—	—

* Unified Soil Classification System.

** Based on height of capillary rise.

1 = Best; 13 = Worst.

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APPENDIX A

SUGGESTED FORM WATCHERS REPORT
AND PROGRAM

SUGGESTED FORM WATCHERS REPORT

Job location ______________________ Date ______________

Placement description: Floor ______________ General Contractor ______________

Placement Number ______________ General Contr. Supt. ______________

Column line references ______________

Starting time of placement: ______________________________

Completion time of placement: ______________________________

Concrete placing equipment: ______________________________

Concrete conveying equipment: ______________________________

Type of work being poured ______________________________

Scope of subcontractor's work ______________________________

Type of formwork or structure to which subcontractor's work is framed ______________________________

Comments on general contractor's framing ______________________________

____

List of points to check out before and during concrete placement

- ___Form details
- ___All shores in place
- ___Wedges under shores tight and nailed
- ___Shoring hardware secured
- ___Sills solid on ground or slab
- ___Lacing installed, when required
- ___Pans nailed
- ___Check for spreaders when required in joist pans
- ___Plywood joints flush
- ___X-bracing installed where lateral movement could occur
- ___Beam spreaders in place
- ___Form hardware tight
- ___Tighten wedges under shores along construction joint of previous pour
- ___Check shores for plumb
- ___Telltales in place and marked where required by superintendent
- ___Camber installed
- ___Clean out holes patched
- ___Chamfer and grade strips in place
- ___Equipment available in case of need for adjustment of reinforcement
  - ___Extra jacks
  - ___Extra shores
  - ___Extra lacing
  - ___Wedges
- ___Prearranged signal with concrete placing foreman to stop pour in emergency
- ___Check for possible exit routes in case of trouble - at least two such routes should be available wherever possible
- ___Know placing crews' sequence of pour. Check for placing deep beams or drops before main deck
- ___For walls: know rate of placement for which forms designed and protest if exceeded

____

______________ Form watcher's signature

______________ Date

______________ Job name

______________ Job no.

Formwork Check Items

1. Types and strengths of materials for formwork
2. Formwork construction loads
3. Limits on rate of pour and concrete temperature
4. Planned pour sequence and schedule
5. Complete formwork details and dimensions
6. Joint details
7. The complete shoring and reshoring plans
8. Safe working areas and passageways to and from the work areas
9. Good housekeeping for safe work areas and passages
10. All perimeter edges and floor openings guarded
11. Personal safety equipment provided for all workers
12. Safe power tools provided
13. Formwork rigging connections checked for correct installation
14. All loose hanging forms removed during stripping operations
15. Exposed nails from stripped forms removed or bent
16. Exposed form ties in work area bent or removed
17. Inspection to ensure that the forming system is complete in all details before placing concrete
18. Lateral bracing, properly attached, provided as shown on the drawings
19. Bulkheads braced to resist lateral pressure and spreading of walls
20. Forms checked to ensure that they are adequately tied and braced
21. Exterior corners tied to prevent spreading
22. All wall ties checked for proper strength, spacing, and length
23. Resistance provided against uplift for top forms with sloping faces
24. Wales checked for proper spacing
25. One member of double-member wales left continuous across form ties at splices
26. Proper lap provided between forms and previous construction with connecting hardware carefully secured
27. Rate of pour not to exceed that shown on working drawings
28. Experienced form watchers inspecting during the concrete placement
29. Proper vibration when penetrating an earlier lift
30. Individual shores laced both ways with continuous runners, and shoring system braced laterally
31. Timber shoring checked to see that it is sound, properly sized, plumb and not but spliced; hardwood wedges checked to see that they are tight and safety nailed to prevent slippage from vibration
32. Columns poured at least one day ahead of slabs for added lateral stability
33. Pour sequence schedule observed, as shown on formwork drawings, to prevent eccentric loadings
34. High drops from concrete buckets and ponding of concrete on supported forms prohibited
35. Concrete slabs allowed adequate time to develop strength before removal of shores or reshores

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Recommendations are provided for general design criteria and specific design review criteria covering the design, construction and operation of the earth-mounded concrete bunker (EMCB) alternative method of low-level radioactive waste (LLW) disposal. An EMCB consists of a below grade reinforced concrete bunker and an above grade tumulus. The reinforced concrete bunker is constructed in an excavation that is located below the freeze line on a pervious foundation blanket. Pervious fill material is compacted adjacent to the bunker in the excavated area and the top of the bunker is covered with a low permeability material.

The above grade tumulus built over the bunker consists of stacked waste containers that are covered initially with pervious fill and then a layered waste cover system. The EMCB includes filter and drainage systems that are connected to monitoring sumps.

Eight major review criteria categories are identified in the report. The categories include (1) the loads and load combinations to be used in design, (2) structural design and analytical methods, (3) construction material quality and durability, (4) construction and operations, (5) quality assurance, (6) structural performance monitoring, (7) filter and drainage systems, and (8) waste cover system.

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